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AIR TRANSPORT
HIGHWAY
PIPELINE
URBAN TRANSPORTATION

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DISCUSSION

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INFORMATION RETRIEVAL

The key words, abstract, and reference "cards" for each article in this Journal represent part of the ASCE participation in the EJC information retrieval plan. The retrieval data are placed herein so that each can be cut out, placed on a 3 × 5 card and given an accession number for the user's file. The accession number is then entered on key word cards so that the user can subsequently match key words to choose the articles he wishes. Details of this program were given in an August, 1962 article in CIVIL ENGINEERING, reprints of which are available on request to ASCE headquarters.

*Discussion period closed for this paper. Any other discussion received during this discussion period will be published in subsequent Journals.

16483 VEHICLE ACCIDENTS IN HIGHWAY WORK ZONES

KEY WORDS: Accident research; Accident sites; Accident statistics; Accident studies; **Construction site accidents; Highway accident potential; Highway construction; Highway safety;** Maintenance; **Vehicle accidents**

ABSTRACT: The magnitude and characteristics of safety problems associated with moving vehicular traffic through and around highway work zones are examined through an analysis of all of the reported work zone accidents that occurred in Virginia during 1977. The accident characteristics analyzed include: the general and specific location of the accident, time of the accident, roadway and environmental factors, characteristics of the work zone, causes of the accidents, and accident severity. Comparisons were made between the work zone accidents, the entire Virginia accident data base, and the work zone accident characteristics reported by others. An assessment was also made of the consistency and completeness of work zone accident reporting. It was found that: (1) Some aspect of the work zone was cited as the cause of roughly 17 percent of all work zone accidents; (2) there was substantial evidence of a rear end accident problem in work zones; and (3) there was an overrepresentation of work zone accidents in urban areas.

REFERENCE: Hargroves, Bradley T. (Asst. Prof. of Civ. Engrg., Univ. of Virginia, Charlottesville, Va.), "Vehicle Accidents in Highway Work Zones," *Transportation Engineering Journal,* ASCE, Vol. 107, No. TE5, **Proc. Paper 16483**, September, 1981, pp. 525-539

16487 TRANSPORTATION TAXATION POLICIES FOR VIRGINIA

KEY WORDS: Econometrics; **Fuel consumption; Highway taxation; Revenues;** Taxation; **Taxes;** Transportation system financing; Vehicles; **Virginia**

ABSTRACT: Improving the revenue base of the Virginia Division of Motor Vehicles by means of changes in the transportation tax system is explored. An econometric forecasting model was developed to project the potential revenues from Virginia's motor fuel sales tax, vehicle sales and use tax, and registration fee system. Among the options explored are: increases in the tax per gallon of motor fuel, a fuel sales tax indexed to gasoline prices, an ad valorum fuel tax, in addition to the current tax per gallon, increases in addition to the current tax per gallon, increases in the percent vehicle sales and use tax, and increases in registration fees. Although each scheme had its advantages and disadvantages, it was found that the most productive and least politically awkward way of stabilizing the Division of Motor Vehicle revenue base is probably an increase in the vehicle sales and use tax.

REFERENCE: Hobeika, Antoine G. (Assoc. Prof., Dept. of Civ. Engrg., Virginia Polytechnic Inst. and State Univ., Blacksburg, Va. 24061), Gordon, Fred, and Tran, Thanh, "Transportation Taxation Policies for Virginia," *Transportation Engineering Journal,* ASCE, Vol. 107, No. TE5, **Proc. Paper 16487**, September, 1981, pp. 541-561

16485 400LB/HP TRUCK ON GRADES

KEY WORDS: **Highway engineering; Highways; Roads;** Speed; Tractive forces; **Traffic;** Traffic capacity; Trucks; **Vehicles; Velocity**

ABSTRACT: A set of equations has been developed which successfully approximates the information for 400 lB/h(240 kg/kW) trucks contained in graphs in the AASHTO Policy on Geometric Design of Rural Highways (1965). The equations make possible the computerized generation of a speed profile along a given grade line and could be used in assessing the effects of a variety of traffic patterns on highway capacity and level of service. Problems such as route comparisons, the effect of grade line variations and location of crawler lanes can be treated conveniently.

REFERENCE: Todres, Hyman A. (Instr., School of Civ. Engrg., Georgia Inst. of Technology, Atlanta, Ga. 30332), "The 400-lb/hp Truck on Grades: Numerical Approach," *Transportation Engineering Journal,* ASCE, Vol. 107, No. TE5, **Proc. Paper 16485**, September, 1981, pp. 563-567

16484 AIRPORT CATCHMENT AREAS

KEY WORDS: **Airports;** Air traffic; **Air transportation; Canada; Model studies; Passenger transportation;** Population density; Reliability; Statistical analysis; Urban areas; **Zoning**

ABSTRACT: Air passenger demand modelling is explored for domestic trips between centers of high population in Canada. The research involves a comparison of two methods of zoning. One method considers the domestic Canadian market as comprising 21 zones, each corresponding to a major city. The other zoning method defines 13 large catchment areas, each of which includes all areas served by airports situated within it. This approach yields markedly improved results, and it is the foundation for the derivation of econometric models relating the demand for air travel to such socioeconomic factors as population mean incomes and air fares. Statistical tests confirm the validity and reliability of these models, but another variable could be justifiably defined as a community-of-interest/time measure between area pairs. Its inclusion in the model building process improved the results even further. A number of demand models are then further developed.

REFERENCE: Moore, O. E. (Transportation Engr., British West Indian Airlines, Trinidad), and Soliman, A. H., "Airport Catchment Areas and Air Passenger Demand," *Transportation Engineering Journal,* ASCE, Vol. 107, No. TE5, **Proc. Paper 16484**, September, 1981, pp. 569-579

16522 BAYSIAN UPDATING OF TRIP GENERATION PARAMETERS

KEY WORDS: Bayes theorem; Sampling; Small cities; **Transportation planning;** Travel demand; **Trip generation;** Urban areas; **Urban transportation**

ABSTRACT: The use of "borrowed" models from similar urban areas is one way of reducing the costs associated with conducting full-scale travel surveys. However, in order to "tune" borrowed models to reflect the local conditions of the study area, these models can be updated using low-cost information (objective or subjective) from the study area. A method based on Bayesian statistics for updating cross-classified household trip generation rates is presented. Some updating techniques are briefly reviewed. Previous applications of Bayesian statistics in the transportation field are also discussed; a methodology for their use to update cross-classified trip rates is presented along with sample application.

REFERENCE: Mahmassani, Hani S. (Research Asst., Mass. Inst. of Technology Cambridge, Mass. 02139), and Sinha, Kumares C., "Baysian Updating of Trip Generation Parameters," *Transportation Engineering Journal,* ASCE, Vol. 107, No. TE5, **Proc. Paper 16522**, September, 1981, pp. 581-589

VEHICLE ACCIDENTS IN HIGHWAY WORK ZONES

By Bradley T. Hargroves[1]

(Reviewed by the Highway Division)

INTRODUCTION

As additional emphasis is placed on improving and rehabilitating in-service highways, the safety of the motoring public in highway work zones is becoming an issue of increasing importance. A number of studies have addressed various aspects of work zone safety; however, nearly all have been based on very limited data and provide little indication of the scope of the work zone accident problem. This paper summarizes the findings of a study undertaken to determine the magnitude and characteristics of motor vehicle accidents in highway work zones using cross-sectional data (3). Based on all of the work zone accidents reported in Virginia during 1977, the analysis includes an examination of both environmental and causal factors as well as the identifiable characteristics of the work zones. Where possible, comparisons were made between the Virginia work zone accidents, the entire 1977 Virginia accident data base, and the work zone accident characteristics reported in the literature. The analysis includes an assessment of the completeness and consistency of work zone accident reporting.

STUDY APPROACH

The data base used for the analysis consists of 2,127 work zone accidents reported in Virginia during 1977. This represents approximately 1.5% of the 142,270 accidents reported in the state for that year. Of the 2,127 work zone accidents, 1,847 were associated with construction activities and 280 with shorter term maintenance and utility type work.

The analysis includes a breakdown of accidents by the variables regularly coded on the Motor Vehicle Accident Report, e.g., time of accident, roadway alignment, weather conditions, etc., as well as a number of additional items that were manually coded from the Accident Description and Accident Diagram

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Note.—Discussion open until February 1, 1982. To extend the closing date one month, a written request must be filed with the Manager of Technical and Professional Publications, ASCE. Manuscript was submitted for review for possible publication on October 9, 1980. This paper is part of the Transportation Engineering Journal of ASCE, Proceedings of the American Society of Civil Engineers, ©ASCE, Vol. 107, No. TE5, September, 1981. ISSN 0569-7891/81/0005-0525/$01.00.

sections of the report. These latter items provided information on the location of the accident within the work zone, the specific relationship between the accident and the work zone activity, and the relationship between the accident and traffic congestion. The analysis was also used to identify interactions between selected variables and the significance of various data stratifications.

The summary of the accident data analysis is presented in the next four sections, i.e., General Accident Information, Causal Factors, Characteristics of the Work Zone, and Accident Severity. This is followed by an analysis of the completeness and consistency of work zone accident reporting and a presentation of the conclusions and recommendations from the study.

General Accident Information.—The data used to describe the general characteristics of the work zone accidents include the time and location of the accidents, the roadway alignment and surface conditions, and the weather and light conditions. All of the information for these items was taken from the data regularly coded on the accident reports.

For the time analysis, all of the work zone accidents were identified by month, day of the week, and time of day. As expected, the work zone accidents were more frequent in the warmer months, i.e., when regular work activity typically is scheduled, than they were during the rest of the year. From March to August, work zone accidents occurred at a fairly constant rate of 205 per month; from September to February, there was an average of 149 accidents per month.

Examination of the daily distribution of accidents showed, not unexpectedly, an overrepresentation of work zone accidents during the Monday through Friday workweek. In contrast, all 1977 Virginia accidents exhibited a distinct weekend peak.

The breakdown of accidents by hour of the day showed a very close agreement between the work zone and all 1977 Virginia accidents. In both cases there was a small peak during the typical morning traffic peak (7–9 a.m.); the number then rose fairly steadily to late afternoon (3–5 p.m.), then dropped off rapidly. While the patterns were nearly identical, there were relatively fewer work zone accidents in the late evening and early morning and relatively more work zone accidents from midmorning (10 a.m.) to midafternoon (3 p.m.). This was a result, no doubt, of the relatively larger amount of work activity that occurs during this time period.

The breakdown of accidents by urban-rural classification showed that there was an overrepresentation of work zone accidents in urban areas and an overrepresentation in the number of fatalities and injuries in urban work zones. Specifically, for all 1977 accidents, urban areas accounted for 51.9% of the total number of accidents and 23.3% of the death- and injury-producing accidents. For the work zone accidents, urban areas accounted for 60.9% of the total and 61.5% of the death and injury accidents. This predominance of urban work zone accidents is also shown by the fact that 33% of the work zone accidents were identified as having occurred in business-industrial areas compared to 19.2% for all 1977 accidents. As a result, urban work zone accidents may constitute a considerably more serious problem than work zone accidents in nonurban areas.

An examination of accidents by type of roadway alinement, e.g., level-straight, grade-curve, hillcrest-straight, etc., showed extremely close agreement between the work zone accidents and all 1977 accidents. No evidence could be found

that specific zone problems exist in any particular alinement condition.

Accidents are broken down by road surface condition in Table 1. While there were similar patterns for the work zone accidents and all accidents, the notable difference was that work zone accidents were more common on dry pavement and less common for other conditions. In addition, an examination of accidents by weather condition showed that 68.6% of the work zone accidents occurred on clear days compared to 58.2% for all 1977 accidents.

The lower percentage of work zone accidents on wet, icy, and snowy pavement suggests that motorists are more cautious under these circumstances or that

TABLE 1.—Accidents by Road Surface Condition

Surface condition (1)	All 1977[a]		Work Zone	
	Number (2)	Percentage (3)	Number (4)	Percentage (5)
Dry	101,877	72.7	1,728	81.5
Wet	28,625	20.4	313	14.8
Icy	6,938	5.0	33	1.6
Muddy	153	0.1	17	0.8
Snowy	2,377	1.7	15	0.7
Oily	184	0.1	13	0.6
Not stated	2,116	—[b]	8	—[b]
Total	142,270	100.0	2,127	100.0

[a]Taken from ref. 10.
[b]Not included in percent calculations.

TABLE 2.—Accidents by Type of Vehicle

Type of vehicle (1)	All 1977[a]		Work Zone	
	Number (2)	Percentage (3)	Number (4)	Percentage (5)
Passenger car	203,423	80.3	2,978	77.0
Large vehicles (trucks tractor-trailers and buses)	39,668	15.7	775	20.0
All Others and Not Stated	10,122	4.0	116	3.0
Total	253,213	100.0	3,869	100.0

[a]Taken from ref. 10.

work zone activity is typically curtailed under adverse weather conditions, or both. Not shown in the table is the fact that 40% of the work zone accidents on muddy and oily surfaces occurred in maintenance and utility areas. A reexamination of the accident reports showed that the adverse surface conditions were often the result, directly or indirectly, of the work activity.

An examination of the breakdown of accidents by light condition showed that 69.4% of the work zone accidents occurred during daylight compared to

63.4% for all 1977 accidents. This was a result, no doubt, of the fact that more work was performed under daylight than under other conditions.

The variables used to describe the type of accident include vehicle type, type of crash, type of fixed object hit, and vehicle action. Table 2 shows the breakdown of accidents by vehicle type for both work zone and all 1977 accidents. As can be seen, the only notable difference is the overrepresentation of larger vehicles involved in work zone accidents. An examination of the accident reports showed that this resulted, in part, from the involvement of construction equipment

TABLE 3.—Accidents by Type of Crash

Type of crash (1)	All 1977[a]		Work Zone	
	Number (2)	Percentage (3)	Number (4)	Percentage (5)
Other motor vehicle	100,232	70.5	1,508	70.9
Noncollision	32,631	22.9	348	16.3
Fixed object	3,959	2.8	221	10.4
Pedestrian	2,052	1.4	27	1.3
All others and not stated	3,396	2.4	23	1.1
Total	142,270	100.0	2,127	100.0

[a]Taken from ref. 10.

TABLE 4.—Work Zone Accidents by Type of Fixed Object Hit

Type of fixed object (1)	Number (2)	Percentage (3)
Bank or ledge	26	7.1
Trees	17	4.7
Utility pole	26	7.1
Fence or fence post	11	3.0
Guardrail or post	25	6.8
Highway structure	65	17.8
Signs, traffic signals	13	3.6
Construction barricades, barriers and signs	123	33.7
Construction equipment or vehicles	59	16.2
Not stated or not applicable	1,263	—[a]
Total	1,623	100.0

[a]Not included in percent calculations.

in work zone accidents. In addition, there were some cases where large vehicles had difficulty negotiating work areas because of reduced geometric standards or driver inattention, or both e.g., driver not noticing lane closure.

Table 3 shows that just over 70% of all crashes involved vehicles hitting other vehicles for both the work zone and 1977 accidents. More importantly, however, these data show that relative to 1977 crashes, work zone accidents involved fewer noncollision type accidents and more fixed object type. For the Virginia work zones, the most prevalent type of fixed object hit included

work area barriers and signs; 33.7% as shown in Table 4. The category "Construction Equipment or Vehicles" accounted for another 16.2% of the fixed objects hit.

The high incidence of fixed object type crashes and the unsafe movement of work vehicles has been documented as problems in a number of case studies (3). More specifically, Nemeth and Migletz (6) have shown that 37.1% of construction accidents in Ohio involved the striking of a fixed object, and that 27.8% of the total number of work zone accidents involved the striking of construction barriers or signs.

Further information on the type of crash was derived from the directional analysis presented in Table 5. The most common work zone accidents, the same-direction-intersection crashes (16.2%), were typically sideswipe accidents often caused by reduced shoulder or lane width. Compared to 1977 accidents, there was an overrepresentation of work zone accidents in the nonintersection subcategories of rear end, stopped in traffic, and fixed object in road. A manual review of the accident reports showed that where a positive determination could be made, 34.5% of the accidents were rear end crashes. This is nearly double the roughly 18.0% rear end crashes reported for 1977 accidents. Nemeth and Migletz (6) have also shown a high incidence of rear end accidents in rural construction areas (40.4%).

Causal Factors.—Several factors relating to the cause of the work zone accidents were identified. These include the principal cause of the accident, traffic violations, driver and pedestrian actions, the relationship between the accidents and traffic congestion, excessive speed, and drinking.

Table 6 shows that the primary cause of 82.8% of the work zone accidents was driver error; more specifically, over 65.0% of the accidents were listed as driver inattention. By comparison, Nemeth and Migletz (6) found that driver error was responsible for 86.1% of construction zone accidents. Nationwide, 89.4% of all accidents have been related to "improper driving" (1).

In only 17.2% of the accidents was a particular aspect of the work zone cited as the primary cause. More than half of these (56%) were due to unsafe movement of work vehicles and road defective and debris in road. A number of other studies have also shown that vehicles entering and leaving the work area cause a significant accident problem (8).

An examination of the accident reports revealed that the unexpected presence of a flagman or construction signal caused a notable problem. Typically, the difficulty did not involve the first vehicles, but rather the following vehicles as the queue built up through the work area. This finding tends to indicate adequate traffic control for slowing or stopping lead vehicles, but that motorists approaching the congested area are unprepared for the interruptions to free-flowing traffic typical in work areas.

Of the drivers involved in Virginia work zone accidents, 48.2% were cited for some driving violation. In contrast, 51.7% of the drivers in 1977 accidents were cited. The patterns of driver violations for the work zone and all 1977 accidents were quite similar, with the exception that the following too close violations were more prevalent for the work zone accidents, i.e., 22.4% vs. 13.3%. This finding ties in well with the high incidence of rear end collisions shown earlier. In contrast, the Nemeth and Migletz study (6) showed only a 10% incidence of following too close.

TABLE 5.—Type of Crash by Location

Vehicle action (1)	All 1977[a] Number (2)	All 1977[a] Percentage (3)	Work Zone Number (4)	Work Zone Percentage (5)
Intersection crashes				
Entering at angle	22,495	15.8	231	10.9
From same direction	21,881	15.4	344	16.2
From opposite direction	6,846	4.8	74	3.5
Fixed object in road	690	0.5	21	1.0
Left road	4,617	3.3	56	2.6
Non-intersection crashes				
Head on	1,559	1.1	18	0.9
Angle or sideswipe	11,796	8.3	222	10.4
Rear end	4,632	3.3	176	8.3
Parked	8,373	5.9	472	2.2
Stopped in traffic	7,553	5.3	256	12.0
At alley or driveway	14,589	10.2	130	6.1
Fixed object in road	3,273	2.3	200	9.4
Overturned	1,866	1.3	20	0.9
Left road	24,680	17.3	240	11.3
All others and not stated	7,420	5.2	92	4.3
Total	142,270	100.0	2,127	100.0

[a]Taken from ref. 10.

TABLE 6.—Principal Cause of Work Zone Accidents

Principal cause (1)	Number (2)	Percentage (3)
Driver error indicated	689	82.8
Driver inattention	547	65.8
Driver under influence	54	6.5
Driver speeding	51	6.1
Driver failed to obey highway signs	11	1.3
All other driver error	26	3.1
Work zone activity error indicated	143	17.2
Unsafe movement of work vehicle	33	4.0
Road defective and debris in road	47	5.7
Flagman related	21	2.5
Poor delineation of work area	17	2.0
Inadequate advance signing; pavement delineation, and advance transition	15	1.8
Barrier left in unsafe position	10	1.2
Unknown	796	—[a]
Total	1,628	100.0

[a]Not included in percent calculation.

In addition to the driver violations, the miscellaneous driver actions identified on the accident reports showed similar patterns for the work zone and 1977 accidents. Not unexpectedly, however, the work zone accidents showed a larger percentage of drivers avoiding other vehicles, i.e., 16.1% versus 12%. An examination of the accident reports showed that this resulted, in part, to the reductions in lane width and the lane closures typical in work zones.

Compared to 1977 accidents, younger drivers were less involved in work zone accidents than older drivers. Specifically for work zone accidents, there was an underrepresentation of drivers in the 20–24 age category. Above that category, older drivers were overrepresented in work zone accidents. This tendency could be interpreted as an indication that younger drivers are more alert or better able to handle unusual or unexpected situations that may be found in work zone areas.

In addition to determining the principal causes of the work zone accidents, a subjective evaluation was made to determine if the cause of the accident

TABLE 7.—Work Zone Accidents by Type of Work

Type of work zone (1)	Work Zone Accidents	
	Number (2)	Percentage (3)
Specific work activity		
Resurfacing	62	50.8
Trenching	11	9.0
Bridge deck repair	10	8.2
Sweeping/washing	3	2.4
Nonspecific shoulder work	13	10.6
Work beyond shoulder	13	10.6
All others	10	8.2
Unknown	1,506	–[a]
Total	1,628	100.0

[a]Not included in percent calculations.

was related to traffic congestion. Using several pieces of information from the accident reports, it was estimated that congestion was at least a contributing factor in 18.1% of the accidents examined. Generally, it was not possible to determine if the congestion was directly caused by the work activity.

An examination was also made of the distribution of vehicle speeds for both work zone and 1977 accidents. This comparison showed that there was an overrepresentation of work zone accidents involving slow moving vehicles, i.e., 40.1% of work zone vehicles travelling less than 15 mph [24 km/h] compared to 36.4% for 1977 accidents. It was also determined that excessive speed (i.e., speed in excess of the speed limit or safe speed) was present in 13.1% of all Virginia accidents, but in only 11.4% of the work zone accidents. This is slightly less than the nationwide average of 14.6% (1) and dramatically less than the 58.3% found in the Ohio Study (6), which involved only high speed, rural locations.

Finally, an investigation of alcohol involvement showed that drinking was evident in 11.4% of the work zone accidents, compared to 13.1% for all 1977 Virginia accidents. At a minimum, this finding suggests that drinking presents no more of a problem in work zones than in the ordinary highway environment.

Characteristics of Work Zones.—The characteristics of the work zones that were examined included the type of work activity being performed, the traffic control used, and the location of the accident within the work zone. Data for

TABLE 8.—Work Zone Accidents by Traffic Control Characteristics

Characteristic (1)	Number (2)	Percentage (3)
Lane(s) closed	204	47.9
Shoulder closed	115	27.0
Flagman/signal	51	12.0
Lane narrowed or partially taken	32	7.5
Work beyond shoulder	13	3.0
All others	11	2.6
Unknown	1,202	—[a]
Total	1,628	100.0

[a]Not included in percent calculations.

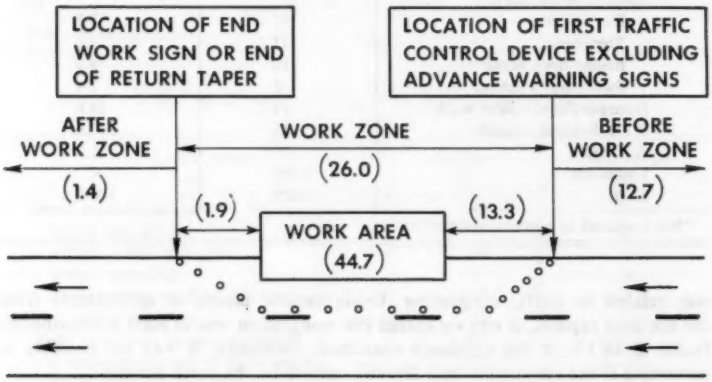

FIG. 1.—Accident Location Within Work Zone

this examination were manually extracted from the "Accident Diagram and Accident Description" sections of the accident reports. Of the 1,628 work-zone accident reports manually reviewed, 62.7% had no information on the work zone in either the accident diagram or accident description. There were 499 work zone accident reports that could not be obtained for the manual data collection.

The type of work activity being performed was identified in only 122 (7.5%)

TABLE 9.—Type of Accident by Location

Location (1)	Percent of total accidents in Virginia (2)	Percent of total accidents in Ohio[a] (3)	Type of accident (4)	Percent of accidents in Virginia (5)	Percent of accidents in Ohio[a] (6)
Before work zone	12.7	15.9	rear end	50.0	58.3
			fixed object	12.5	29.2
			other	37.5	12.5
Approach taper	13.3	22.5	rear end	42.7	23.5
			fixed object	32.0	44.1
			other	25.3	32.4
Adjacent to work area	44.7	16.5	fixed object	28.0	37.5
			rear end	27.7	24.0
			side swipe	18.2	12.0
			other	26.1	26.5
Entire work zone area	85.9	78.1	fixed object	40.8	44.0
			rear end	28.6	42.9
			other	20.6	13.1

[a]Taken from ref. 6.

TABLE 10.—Accidents by Severity

Type of accident (1)	All 1977[a]		Work Zone	
	Number (2)	Percentage (3)	Number (4)	Percentage (5)
Total accidents	142,270	100.0	2,127	100.0
Fatal	998	0.7	12	0.6
Injury	39,802	28.0	535	25.1
Property damage	101,470	71.3	1,580	74.3

[a]Taken from ref. 10.

TABLE 11.—Average Accident Severity

Severity index (1)	All 1977 (2)	Work zone (3)
Number of persons killed or injured per accident	0.411[a]	0.359
Number of pedestrians killed or injured per accident	0.0160[a]	0.0156
Number of vehicles involved per accident	1.78[a]	1.82
Average property damage per accident	$1,104[b] rural	$1185 rural
	—	$1047 urban
	—	$1091 average

[a]Taken from ref. 10.
[b]Taken from ref. 9.

TABLE 12.—Summary of Work

Study source (1)	Data date (2)	Number of projects (3)	Number of Work Zone		
			Total (4)	PDO (5)	(6)
Arizona[a]	1969	All rural work zones	278	155	(55.7)
California[b]	1965	10	745	383	(51.4)
California[c]	1970	31	4,927	2,890	(58.6)
Ohio[d]	1972–1974	21	151	99	(65.6)
Texas[e]	1960	All rural work	1,724	—	—
	1961	zones	1,647	—	—
	1962		1,500	—	—
	1963		1,573	—	—
	1964		2,184	—	—
	1965		2,063	—	—
	1966		2,394	—	—
	1967		2,704	—	—
Virginia[e]	1960	All work zones	574	—	—
	1961		881	659	(74.8)
	1962		971	709	(73.0)
	1963		1,109	830	(74.9)
	1964		1,319	1,003	(76.0)
	1965		1,814	1,415	(78.0)
	1966		1,763	1,356	(76.9)
	1967		1,734	1,308	(75.4)
Virginia	1977	All work zones	2,127	1,580	(74.3)
Wyoming[e]	1962	All work zones	127	—	—
	1963		108	—	—
	1965		100	—	—
	1966		118	—	—

[a]Taken from Ref. 2.
[b]Taken from ref. 7.
[c]Taken from ref. 4.
[d]Taken from ref. 6.
[e]Taken from ref. 5.

of the 1,628 reports examined. As shown in Table 7, roughly half of those identified were resurfacing operations. Another 40.0% were split nearly equally between trenching, bridge deck repair, nonspecific shoulder work, and work beyond the shoulder.

Table 8 summarizes several types of traffic control used in the work zone. Nearly half of the cases where a determination could be made involved a lane closure. Another quarter of the cases involved a shoulder closure.

One of the more instructive aspects of the analysis of the characteristics of the work zone concerned the location of the accident within the work zone. For this analysis, the area surrounding a typical work area was divided into six overlapping areas (Fig. 1). Using the information in the accident diagram and the accident description, locations for 566 of the 1,628 accidents reviewed were determined.

Zone Accidents By State

Accidents (Percent)				Number of Persons	
Injury		Fatal		Injured	Killed
(7)	(8)	(9)	(10)	(11)	(12)
112	(40.3)	11	(4.0)	235	18
334	(44.8)	28	(3.8)	—	35
1,954	(39.7)	83	(1.7)	—	106
49	(32.4)	3	(2.0)	—	—
—	—	60	(3.5)	—	—
—	—	49	(3.0)	—	—
—	—	50	(3.3)	—	—
—	—	56	(3.6)	—	—
—	—	53	(2.4)	—	—
—	—	30	(1.5)	—	—
—	—	53	(2.2)	—	—
—	—	54	(2.0)	—	—
—	—	4	(0.7)	—	—
217	(24.6)	5	(0.6)	—	—
247	(25.5)	15	(1.5)	—	—
272	(24.5)	7	(0.6)	—	—
307	(23.3)	9	(0.7)	—	—
383	(21.1)	16	(0.9)	—	—
394	(22.4)	13	(0.7)	—	—
447	(25.8)	9	(0.5)	—	—
535	(25.1)	12	(0.6)	750	13
—	—	—	—	76	3
—	—	—	—	54	4
—	—	—	—	91	3
—	—	—	—	86	6

As shown in Fig. 1, slightly less than half of all of the accidents located (44.7%) occurred in the roadway immediately adjacent to the work area, excluding the approach and closure tapers. The region immediately before the work area, the approach taper region, was the scene of the next highest percentage, with at least 75 accidents (13.3%). An additional 26% of the accidents were identified as occurring in the general area designated as "work zone"; however, it could not be determined whether these accidents occurred in the approach taper, work area, or closure taper. Consequently, the aforementioned figures should be interpreted as minimum values.

Further examination of the accident locations showed that each of the general work zone regions exhibited different types of accident patterns. In terms of absolute numbers of accidents, rear end and fixed object accidents were most frequent in the area immediately adjacent to the work area. However, it was

not unexpected that rear end accidents, the most prevalent type, made up a larger percentage of the accidents in the areas in advance of the actual work area. Fixed object accidents, the second largest type, occurred with nearly equal percentages throughout the entire work area.

Similar data were generated by Nemeth and Migletz (6) and are shown in Table 9. The region descriptions differed slightly but were generally the same as those described above. A comparison of the two data bases showed that, relative to the Ohio study, Virginia had (1) Fewer fixed object and rear end accidents before the work zone; (2) fewer accidents in general in the approach taper region, including relatively more rear-end and relatively fewer fixed-object accidents; (3) fewer fixed-object accidents immediately adjacent to the work area; and (4) fewer rear-end accidents in the entire work area region.

Accident Severity.—A variety of indicators were selected to evaluate the relative severity of the work zone accidents. As shown in Tables 10 and 11 the average work zone accident was slightly less severe than the average 1977 accident when compared by the percentage of property damage only (PDO) accidents and the numbers of persons killed or injured per accident. The average work zone accident was slightly more severe, however, than the average 1977 accident in terms of the number of vehicles involved per accident and average property damage.

Outside the Virginia data base, little data have been published on work zone accident severity and comparisons are complicated by different reporting procedures. Nevertheless, the limited data available do show a much greater proportion of property damage only accidents in Virginia than that reported in Arizona, California, and Ohio (Table 12). In addition, the percentage of work zone accidents involving a fatality has been consistently lower in Virginia than that reported by others.

Completeness and Consistency of Reporting.—In filling out the accident reports, police officers are instructed to indicate any road defects that contribute to the accident by checking off the appropriate item in the Roadway Defects block. The possible response options include under repair, loose material, holes, ruts, bumps, soft or low shoulders, and no defects. For the case in which multiple responses are possible, the officer is instructed to indicate the one item considered to have contributed most to the accident or that best describes its cause. For example, if the defect could be classified as soft or low shoulders and under repair, the officer would have to decide which best describes the cause of the accident. From noting the different items in the road defects block and discussions with training officers, it was assumed that some accidents, which could be identified as under repair, were, in fact, classified under a more explicit classification in the roadway defects block.

A questionnaire was used to determine the specific circumstances in which the under repair designation was being used. Specifically, the questionnaire was designed to determine the proportion of officers that would check off under repair in a variety of work zone and accident scenarios. A total of 135 questionnaires were used in the analysis. They were completed by state and local police representing a variety of experience and areas of regular patrol, i.e., urban and rural. The results of the questionnaire indicated that the officers were more likely to check off under repair when (1) The work activity was in or physically on the roadway, thus necessitating a lane closure; (2) when

there was work related debris in the roadway; and (3) when there was a malfunction in the traffic control system. The questionnaire also showed that the officers were less likely to check off under repair when the work activity was not physical repair of the roadway, e.g., sweeping, tree trimming, surveying, mowing, landscaping, and sign replacement, and when the first event in the accident sequence was not related to the work area, e.g., vehicle runs off road and hits some component of the work area. As a result, there were a variety of cases in which accidents actually occurred in a work zone and as the result of the work zone, but were not designated as under repair. Based on the characteristics of the work zone, i.e., distribution of accidents by type of work activity, and the completeness of reporting information obtained from the questionnaire, it is estimated that there were actually 2,600 under repair accidents in Virginia in 1977. (This estimate does not take into account unreported accidents.) The difference between this number and the reported figure of 2,127 represents a weighted average completeness of reporting ratio of roughly 0.82.

Conclusions and Recommendations

Based on the results of the investigation, the following conclusions and recommendations are made.

1. In Virginia, the under repair designation is an effective means of identifying work zone accidents. While it was estimated that roughly one-fifth of the accidents occurring in work zones were not identified because they did not carry the under repair designation, those accidents typically involved work not actually in the travelled way and were caused by factors not related to the work zone.
2. There is substantial evidence of a rear-end accident problem in highway work zones. An analysis of the problem showed that approaching motorists are generally unprepared for the interruptions to free-flowing traffic typical in many work areas. There did not appear to be any problems related directly to the methods used to slow or stop traffic; nor could any highway capacity problems be directly attributed to the work operations. Nevertheless, it is recommended that traffic control plans be designed for work zones, where practical, to eliminate bottlenecks, minimize speed reductions, and minimize interruptions to what would otherwise be free-flowing traffic conditions. It is also recommended that research be undertaken to determine (1) How much additional caution or awareness motorists should be expected to exercise in work areas; and (2) what methods are most effective in communicating this need for additional caution or awareness to the motorist.
3. There are accidents in work zones that can be avoided without extraordinary cost by improving work zone practices and procedures. The unsafe movement of work vehicles and the presence of road defects and debris are both common and inexpensively correctable problems. In order to reduce the number of accidents caused by these, as well as other work zone problems, it is recommended that (1) Specific standards and guidelines be developed for the access and egress of work vehicles from the work area; (2) work area personnel be trained in the fundamental principles of work zone safety; and (3) inspection procedures be included as part of the work zone traffic control plan.
4. The reason for the slight overrepresentation of work zone accidents in

urban areas was not apparent from the data contained on the accident reports. Consequently, it is recommended that a study be undertaken to examine the special problem of urban work zones. At a minimum, this study should consider: (1) Any problem with the target value of traffic control devices in the urban environment; (2) the problems created by large information loads put on the driver; and (3) the effect of high volumes of traffic on different traffic control procedures.

5. The results of this study are unique in the level of detail presented and the fact that the data represented a full year of work zone accidents for an entire state rather than those for a select group of work sites. While the results fill a critical gap in the body of knowledge concerning work zone accidents, there are insufficient data available to allow precise conclusions on a national scale. Consequently, it is recommended that current efforts to assemble information on work-zone accidents be continued. There are particular problems, however, in using historical accident data. First, typical work zone accident reports contain very little information on the characteristics of the work zones and the relationships between accidents and work zones. Also, major changes are being made in work zone practices and traffic control procedures such that the true scope of the current accident problem may be reflected only by very current data. Site specific studies using non-accident indicators, e.g., traffic conflicts, may provide a useful direction for future studies.

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TRANSPORTATION TAXATION POLICIES FOR VIRGINIA

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(Reviewed by the Urban Transportation Division)

BACKGROUND

For many years, the State of Virginia has relied on a series of user fees for the provision of funds for the state highway program. Of these fees, the fuel sales tax, the annual vehicle registration fee, and the sales and use tax on vehicles have traditionally carried the burden of the responsibility for the state share of highway expenditures. As seen in Table 1, these three fees currently account for roughly 60%, 15%, and 15%, respectively, of all user fee receipts on an annual basis (1). In recent years, the adequacy of these funding sources to meet the needs of the state for highways and highway services has undergone a steady erosion, especially with the escalated increase in highway construction price index. In the course of this paper, different taxation policies are analyzed, and their effects on Division of Motor Vehicle (DMV) revenues are documented. Specifically, several methods of increasing tax revenues through changes in the user fee system received close scrutiny. Among the alternatives considered were increases in the state tax per gallon of gasoline, price indexing for the gasoline sales tax, an ad valorum tax on the sale of gasoline, a differential tax for diesel fuel, and increases in the registration fees and the sales and use tax.

The potential impact of each of these changes on revenues was explored by use of the Virginia Division of Motor Vehicles Revenue Model. This model, which is extensively documented in earlier reports submitted to the Virginia DMV (2,3,4,5) was designed to predict future revenues for the Virginia DMV under different future socio-economic conditions. The forecasting model is an econometric model based on a series of regression relationships that describe

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the influence of future socio-economic conditions on vehicle-related user fee revenues. The model was developed under the assumption that population and economic factors are the major forces that affect travel behavior, vehicle ownership, and vehicle use and, in turn, influence the tax revenue potentials. Both population and economy affect travel and automobile purchases. New car purchases affect the age distribution of the total auto fleet, which subsequently determines the overall miles per gallon of fuel usages. Multiplying this figure by the amount of yearly vehicle miles of travel gives the total automobile fuel consumption. This consumption, when multiplied by the tax rate, gives the annual fuel tax revenues. In addition, population and economy affect the number of vehicles registered in the state and the new and used vehicles purchased, by influencing the driving age population—those persons 16 years of age and older—who can afford to own and operate a car. Sales and use tax revenues are determined by applying the 2% tax rate to the total sales value of the vehicles, where revenues from registrations are determined by multiplying the number of vehicles registered in each class (automobile, bus, truck, motorcycle, and trailer) by their respective average fees.

TABLE 1.—Motor Vehicle Revenues from Virginia Taxes for FY 1977–78

Revenue source (1)	Revenues (2)	% of Revenues (3)
Motor Vehicle Fuel Tax	$274,953,000	58.70
Motor Vehicle Sales and Use Tax	$58,896,000	14.71
Motor Vehicle Registration	$70,658,000	15.09
Other Fees	$53,867,000	11.50
Total	$468,347,000	100.00

The model consists of five basic submodels: economy, population, vehicle-miles of travel, vehicle registration, and new and used vehicle purchases. The mathematical relationships that formulate these submodels calibrated for 1978 data are discussed briefly herein. However, a more complete discussion of the model, its components, equations, and variables are found in detail elsewhere in several documents (2, 3, 4, 5, 6, and 7).

Economic Submodel.—Total personal income (PI) in the state is one factor in the economy of main concern in traveling and car buying. Several attempts have been made to develop a simple and realistic model to forecast total personal income using various independent variables, such as total discounted capital stock in manufacturing (TDCSM), current dollars of manufacturing investment, and overall consumer price index (CPIOC). The analysis showed that TDCSM gave the best fit for the data, and the resultant relationship was

$$PI = 3.631e^{0.569TDCSM}, \quad R^2 = 0.9983. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Population Submodel.—Based on the 1960–1970 Virginia population data, future population is assumed to grow at 1% per year, and future household size to decline at 0.79% per year.

Travel Submodel.—Total vehicle miles of travel in Virginia is disaggregated into three travel groups: (1) Travel by in-state households (TVMISH); (2) travel by out-of-state households (TOSVM); and (3) travel by trucks (TTVM). Travel in each of these groups has been considered a function of two major factors, the cost of transportation and the income available to pay these costs. These factors included variables, such as average cost per mile (ACPM), CPIOC, PI, mean household income (AHHI), and number of households in the state (HH). The form of these functions is shown below:

$$\text{TVMISH} = 7.92\ \text{AHHI}^{0.923}\ \text{ACPM}^{-0.732}\ \text{HH} \quad R^2 = 0.950 \quad \ldots\ldots\ldots\ (2)$$

$$\text{TOSVM} = \left[6704 - 6282.5 \times 10^3 \left(\frac{\text{ACPM}}{\text{AHHI}}\right)\right] \text{HH}, \quad R^2 = 0.83 \quad \ldots\ldots\ (3)$$

$$\text{TTVM} = -5.481 \times 10^9 + 77.11 \left(\frac{\text{PI}}{\text{CPIOC}}\right), \quad R^2 = 0.974 \quad \ldots\ldots\ldots\ (4)$$

Registration Submodel.—Total vehicle registration is disaggregated into three mutually exclusive categories within the model: (1) Vehicle registration (REG), which includes automobiles, buses, and trucks; (2) motorcycles (MOTO); and (3) trailers (TRAIL). These totals are subsequently used to determine the overall revenue from all vehicle registrations:

$$\text{REG} = 7.134\ \text{PI}^{0.5385}, \quad R^2 = 0.9536 \quad \ldots\ldots\ldots\ (5)$$

$$\text{AUTO} = 0.83876\ \text{REG} \quad \ldots\ldots\ldots\ (6)$$

$$\text{BUS} = 0.0034\ ((1 - 0.01953)^I)\ \text{REG}$$

(in which I = the number of years beyond 1975) $\ldots\ldots\ldots\ (7)$

$$\text{TRUCK} = \text{REG} - \text{AUTO} - \text{BUS} \quad \ldots\ldots\ldots\ (8)$$

$$\text{MOTO} = 3.805 \times 10^{-25}\ \text{DPOP}^{1.6671}\ \text{AHHI67}^{4.506}, \quad R^2 = 0.9045 \quad \ldots\ldots\ (9)$$

$$\text{TRAIL} = 8.076 \times 10^{-13}\ \text{HH}^{1.943}\ \text{AHHI67}^{1.306}, \quad R^2 = 0.989 \quad \ldots\ldots\ (10)$$

New and Used Vehicle Purchases Submodel.—This submodel contains four important equations, which directly relate to sales tax revenues. They are the mean price of new and used vehicles, (PN) and (PU), respectively, and the number of new (NEW) and used (USED) vehicles purchased:

$$\text{PN} = 318585.8 - 163.2\ \text{YEAR} + 54.5\ \text{CPIOC}, \quad R^2 = 0.991 \quad \ldots\ldots\ (11)$$

$$\text{PU} = -84152.9 + 0.091\ \text{PN} + 43.1\ \text{YEAR}, \quad R^2 = 0.984 \quad \ldots\ldots\ldots\ (12)$$

$$\text{NEW} = -2.866 \times 10^5 + 47.20\ \text{PN} + 57.92\ \text{AHHI67} - 2035.64\ \text{CPIGC},$$

$$R^2 = 0.9123 \quad \ldots\ldots\ldots\ (13)$$

$$\text{USED} = -3.181 \times 10^5 + 328.315\ \text{PU} + 54.118\ \text{AHHI67}, \quad R^2 = 0.9827 \quad (14)$$

A comparison of this model with other states' models is also discussed elsewhere (5,8).

By varying the fee structures within the model, the potential impact of changes in the tax system can be seen in terms of changes in the revenue projections. In some cases, the long-term impact of tax increases on automotive fuel

consumption can also be projected, at least to the limited extent that the historic information about consumer response during the last 11 years is adequate to predict consumer behavior in the future.

Problem: Declining Revenues, Increasing Costs

As was shown in Table 1, most of the revenues that come to the Division of Motor Vehicles are from the fuel sales tax, the annual vehicle registration fee, and the vehicle sales and use tax. The following briefly describes each of these three major sources of DMV revenue.

TABLE 2.—Current Registration Fees

Automobiles	$15.00
Buses	$8.00
Trucks	$50.00 (rough average)
Motorcycles	$7.20
Trailers	$20.00

TABLE 3.—Comparison of Increases in DMV Revenues and in Cost Indicators 1970–78 (Expressed as a Percentage of the 1970 Value)

	Revenues				Cost Indicators*		
Year (1)	Registration (2)	Sales and use tax (3)	Fuels tax (4)	Total (5)	CPIOC (6)	CPIGC (7)	HCPI (8)
1970	100	100	100	100	100	100	100
1971	110	122	107	109	104	101	105
1972	117	136	116	118	108	102	110
1973	140	160	123	130	114	112	121
1974	126	146	119	123	127	151	161
1975	146	151	122	129	139	162	162
1976	146	194	130	140	147	171	159
1977	146	225	135.5	147	156	178	172
1978	154	259	141.5	156	165	190	211

*HCPI = Highway Construction Price Index. CPIGC = Consumer's Price Index of Gasoline. CPIOC = Consumer's Price Index of Overall Goods.

Fuel Sales Tax.—A fixed levy is charged on each gallon of motor fuel sold in the State of Virginia. Since 1972, this fee has been nine cents per gallon. A 1-cent hike occurred in 1972 and in 1973 from a tax of 7 cents a gallon, which had been charged in previous years. Another 2-cent hike was added in July 1980, which brings the tax to 11 cents per gallon. The tax applies equally to all forms of motor fuel, be it gasoline, diesel, or alcohol.

Registration Fee.—An annual vehicle registration levy is charged to all vehicles registered in the state. The fee varies depending on vehicle type, as is shown in Table 2. Fees for trucks are levied according to a more complex system

based on weight. The $50 average shown in Table 2 is the rough average used in the DMV Revenue Model. (A 2% tax is levied on all sales of new and used motor vehicles within the state. The tax is 3% for mobile homes, but the additional 1% tax is turned over to localities in lieu of a local real property tax on the dwellings.)

This system of levies was adequate for funding the operations of the Virginia DMV and Department of Highways, as long as consumption of fuel and purchases of vehicles kept pace with highway construction, maintenance costs, and administrative responsibilities. The sales tax revenues increased as auto prices went up. The real value of the tax per gallon of gasoline declined due to inflation, but gasoline consumption increased through the sixties and early seventies. The registration fee also declined in real value due to inflation, but constituted a sufficiently small share of the revenue picture that the revenues were not seriously affected.

However, in the middle and late seventies, the revenue picture deteriorated rapidly in comparison to expenditure inflationary rates. Table 3 shows some highway cost indicators compared to the total revenues from the three sources described in terms of annual percentage increases. As can be seen, the revenues have kept pace with neither highway construction prices nor general prices. The Highway Construction Cost Index, which is an indicator of highway construction inflation rates, increased at an even more rapid rate. The index increased from a rating of 100 in 1967 to 199.3 in 1976, and to 312.4 in 1979 (9). If DMV revenues are compared to income, it can be seen that the burden on Virginia's populace for highway services has been declining as a proportion of income over this same period of time.

Implications

It has become apparent that either transportation tax revenues must go up or highway services and maintenance must decline. This inevitable choice has reached a new urgency within 1980, following the decreases in gas consumption. With gas tax revenues dropping at the same rate as gasoline consumption, the Department of Highways would be forced to substantially reduce their highway construction program if tax increases are not established.

The remaining part of this paper explores several alternatives for increasing DMV revenues, pointing out some of the advantages and disadvantages of each alternative, and forecasting its impact on the Virginia DMV future revenue potential.

Automotive Fuel Sales Tax

Introduction

This section explores the impacts of possible changes in the automotive fuel sales tax on future DMV revenue receipts. Among the changes that are considered are a simple increase in the tax, a gas tax linked in amount to a cost index, and an ad valorum tax.

Since the demand for many highway services and the amount of road wear vary directly with road use, it seems logical that the largest single highway

revenue source for Virginia should be a tax that is proportional to road use. The fuel sales tax has traditionally been considered to be such a user tax, in that its potential to generate revenue varies in rough proportion to the consumer's use of the state's highways. This tax provides the most direct, easily administered, and collectible form of user-related tax. For this reason, all 50 states have some form of the gasoline sales tax. As has been stated earlier, the revenues produced from this tax have not kept pace with expenditures and inflation, especially those experienced in the highway construction industry. As a result, many states have already raised the fuel sales tax in order to increase highway revenues while others are presently considering such a measure. The State of Virginia is in the former category, having recently passed a 2-cent per gallon increase in the fuel sales tax.

The following scenarios were developed by the researchers as tools for evaluating alternative ways of increasing the fuel tax revenues in Virginia.

Scenario A—Graduated Tax Increase.—The first scenario to be considered assumes increases in the fuel sales tax at the rate of 1-cent per gallon every two years. The rate of increase in the fuel sales tax in this scenario represents a considerable acceleration over the historic rate of increase. However, it is still less than the historic rate of increase in gasoline prices, overall prices, or of the DMV and Department of Highway costs over the last decade.

There are two ways in which increases in the fuel sales tax result in changes in DMV revenues. The largest, and most direct, effect occurs as a result of the increased tariff received on each gallon of fuel sold. However, there is a smaller secondary impact, which tends to work in the opposite direction. As the price of gasoline goes up, motorists will use less of it. If the price goes up enough, they will tend to buy and register fewer autos also. Because of this response, the DMV will not collect the full dollar value of the percentage increase in fuel sales taxes. For instance, a 20% hike in the fuel tax will increase revenues from that tax by somewhat less than 20%.

In order to assess the impact of tax increases on consumer spending patterns, the DMV Revenue Model was altered so that tax increases are registered also as increases in the Consumer Price Index of Gasoline Costs (CPIGC). Within the model, the CPIGC influences consumer demand for gasoline and automobiles, because it is an independent variable in the equations to determine new auto purchases (NEW), and average cost per mile (ACPM). New car sales influences the amount of sales and use tax collected. ACPM influences gasoline sales through its appearance as an independent variable in the equations for in-state vehicle miles of travel (TVMISH) and out-of-state vehicle miles of travel (TOSVMT). Vehicle-miles traveled are used in the model to compute gasoline consumption (TGC).

The equation used to incorporate the tax hikes into the CIPGC is:

$$\text{IF (RATE } (I)\text{.NE.RATE}(I-1))\ \text{CPIGC } (I) = \text{CPIGC } (I)$$

$$+\ (\text{RATE } (I) - \text{RATE } (I-1))^{*}\ 100/0.322 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

in which I is the number of years since 1967; RATE is the fuel sales tax rate in dollars/gallon; and 0.322 is the 1967 gas price in dollars.

Revenues from the fuel sales tax under the graduated increase scenario are compared to revenues under the base case scenario from the 9-cent tax in

Table 4. Under the graduated increase scenario, the biennial penny per gallon increases in the fuel sales tax raise the tax from 9 cents in 1979 to 14 cents by 1990. The increases result in higher revenues than those projected for the base case by sizable percentages over time. By 1990, the revenue under the graduated increase scenario is 55.4% higher, a net increase of $181,020,000. Table 4 also shows the net increase in the gas tax rate in percentage terms. The percentage increase in revenues is always lower than the percentage increase in taxes for the corresponding years because of the impact of higher prices of gasoline on travel by autos.

Impact of Increased Gas Tax on Consumption of Gasoline.—In looking at the impact of tax increases on consumer demand, it was decided that attention should be focused primarily on the impact of gasoline consumption. Although

TABLE 4.—Gas Tax Revenues from Graduated Tax Increase Scenario (All Revenue Figures are in Millions of Dollars)

Year (1)	Fuel tax revenues for base case (rate = 9¢) (2)	New tax rate (3)	Fuel tax revenues at new rate (4)	Net revenue increase (5)	Percent increase (6)
1981	281.3	.10	311.4	30.1	11.06
1982	287.4	.10	318.2	30.8	11.07
1983	291.2	.11	353.6	62.4	21.42
1984	295.3	.11	358.6	63.3	21.45
1985	299.7	.12	396.2	96.5	32.20
1986	305.7	.12	404.2	98.5	32.23
1987	313.7	.13	448.5	134.8	42.98
1988	321.1	.13	459.3	138.2	43.02
1989	324.7	.14	504.3	179.6	55.30
1990	326.6	.14	507.7	181.0	55.49

the auto purchase model is affected by the Consumer Price Index of Gasoline (CPIGC), the impact of any foreseeable tax increase on auto sales is considered negligible.

The DMV model ran with some slight structural modifications, in order to determine the impact of decreased duel consumption on DMV revenues. The graduated tax increase scenario was run with and without Eq. 1, simulating the increase in revenues with the presence or the absence of the increase in sales tax on CPIGC, respectively.

As is shown in Table 5, an increase in the tax of 5 cents over a 10-year period has only a slight impact on gasoline demand. The total difference between what revenues would be with and without consumer response to the tax increase amounts to only $24,540,000 over the 10-year period, or 0.6% of fuel tax revenues.

Caution should be used in applying the results of this analysis to larger changes in gasoline prices. The model predicts change in demand based on historic data that is mostly drawn from a period of small, incremental price changes of gasoline. If a change in the price of gasoline occurs that is of a magnitude

larger than those reflected in the historic data, this model may not adequately depict the consumer response to such a change.

It may seem curious that the revenue difference due to the impact of the tax on gasoline demand "tails off" during the last two years, as shown in Table 5. This is because by 1989, the model approaches a predetermined limit on the number of vehicle-miles traveled by in-state households. The limit is set at a maximum of 25,000 mi per yr per household. Once this limit is reached, in-state vehicle-miles can only increase as a result of population increases or decreases in the average household size.

It also seems unusual that the difference between revenues with and without consumer demand response to the new tax decreases slightly the year after each tax increase. This phenomenon is a result of the combination of the 6.4%

TABLE 5.—Impact of Decreased Consumption of Motor Fuel Due to Tax Increases on Motor Fuel Tax Revenues under Graduated Increase Scenario

Year (1)	Tax increase (2)	Gas tax revenues[a] without demand impact on sales (3)	Gas tax revenues[a] with demand impact on sales (4)	Difference in $[a] (5)	Difference as % of revenue (6)
1981	0.01	312.59	311.41	1.18	.38
1982	0.02	319.34	318.17	1.17	.37
1983	0.02	355.89	353.55	2.34	.65
1984	0.01	360.88	358.60	2.28	.63
1985	0.03	399.56	396.16	3.40	.85
1986	0.03	407.53	404.17	3.36	.82
1987	0.04	453.04	448.47	4.57	1.01
1988	0.04	463.87	459.31	4.56	.98
1989	0.05	505.12	504.63	.49	.10
1990	0.05	508.11	507.66	.45	.09

[a]Revenues are in millions of dollars.

annual increase in CIPGC, which is an assumed part of both scenarios and of the nature of the negative logarithmic relationship between gas prices and vehicle-miles traveled in the DMV Revenue Model.

Scenarios B and C—One-Step Fuel Tax Increases.—Another proposal for increasing the fuel sales tax involves the institution of a one-step 4-cent increase on the tax per gallon of motor fuel. This concept was proposed by Governor Dalton in January, 1980, but was later replaced by a 2-cent increase and a 2% local ad valorum tax in Northern Virginia. The main advantage of this tax increase scheme is that it provides a major influx of revenues in a relatively short period of time. Of course, unless there is another major increase in a few years, the revenue yield of the tax once more would fail to keep pace with inflation, especially if the 1980's see a reduction in gasoline demand. The impact of 4-cent and 2-cent gas tax increases, starting in 1981, were evaluated using the DMV Revenue Model.

As Tables 6 and 7 show, the average revenue increase is 42.8% under the 13-cent tax, and 21.5% under the 11-cent tax. However, the annual percent

rise in revenues, due to the growth in tax increases, varies slightly under both scenarios. This is because of the negative logarithmic relationship between CPIGC, the gas price index, and the vehicle miles traveled by in-state vehicles (TVMISH) in the model. As the gas price goes up, the vehicle-miles traveled goes down at a negative exponential rate.

TABLE 6.—Gas Tax Revenues under Four-cent Fuel Sales Tax Increase Scenario (All Revenue Figures are in Millions of Dollars)

Year (1)	Revenues with tax at 9 cents (base case) (2)	Revenues with tax at 13 cents (3)	Net revenue increase (4)	% revenue increase (5)
1981	281.3	400.3	119.0	42.3
1982	287.4	409.1	121.7	42.3
1983	291.2	414.8	123.6	42.4
1984	295.3	420.8	125.5	42.5
1985	300.7	427.4	126.7	42.6
1986	305.7	436.1	130.4	42.7
1987	313.6	447.6	134.0	42.7
1988	321.1	458.5	137.4	42.8
1989	324.7	468.6	143.9	44.3
1990	326.6	471.4	144.8	44.3

TABLE 7.—Gas Tax Revenues under Two-cent Fuel Sales Tax Increase Scenario (All Revenue Figures are in Millions of Dollars)

Year (1)	Revenues with tax at 9 cents (base case) (2)	Revenues with tax at 11 cents (3)	Net revenue increase (4)	% revenue increase (5)
1981	281.3	341.0	59.7	21.2
1982	287.4	348.5	61.1	21.3
1983	291.2	353.2	62.0	21.3
1984	295.3	358.2	62.9	21.3
1985	300.7	363.7	63.0	21.3
1986	305.7	371.0	65.3	21.4
1987	313.6	380.8	67.2	21.4
1988	321.1	390.0	68.9	21.5
1989	324.7	396.7	72.0	22.2
1990	326.6	399.0	72.4	22.2

Although the increase in gas tax revenues is high compared to the base case, the average annual increase in gas tax revenues through the course of the 13-cent tax increase scenario is only 1.8% higher than that under the graduated tax increase scenario.

Scenario D—Ad Valorum Tax.—Another proposal that came under consideration in 1980 was the ad valorum tax or percentage tax on fuel. Under this

scheme, the tax would be waged as a percentage of the price of fuel, instead of a fixed number of cents per gallon. This sort of tax deals with one of the major disadvantages of the present tax on fuels—the requirement for periodic legislative authorization for tax rate increases just to keep buying power at a steady level.

There are several imperfections to the ad valorum tax as a means of keeping revenues apace with highway costs. The first is that gasoline is not necessarily increasing in price at the same rate as highway services. Indeed, gasoline is one of the commodities for which its price is least stable and least under any measure of domestic control. This may result in a highly unstable revenue flow, which would make program planning for the DMV and Department of Highways a logistical problem. Another possible problem is the lack of legislative review for tax increases with an ad valorum tax. Some legislators feel that a program that would allow the highway programs to increase their funding levels without any provision for review of program effectiveness or desirability is not in the public interest.

The initial proposal before the general assembly was for an ad valorum tax of 4% in addition to the present 9-cent per gallon fuel tax. This scheme has the additional feature that would prove only slightly responsive to the increase in gas prices. While the 4% portion of the gas tax would respond to inflation, the initial 9-cent per gallon tax would not. As will be shown below, the net effect would be a net increase in revenues that is not likely to keep pace with cost indices.

Modeling the Ad Valorum Tax.—The modeling of an ad valorum tax structure required some modification of the DMV Revenue Model. It was necessary to compute a tax rate based on 4% of the price of gas and to compute total gas revenues based on that rate. It was also necessary to show the influence of the added tax on consumer behavior, by incorporating the tax increases into the Consumer Price Index of Gasoline Costs.

The first task was accomplished by the addition of two equations to the model. This first equation establishes a 4% tax rate:

$$\text{IF}(I.\text{GE}.13)\text{VRATE(I)} = \text{CPIGC}(I)*.04/.332 \quad (16)$$

in which VRATE is the ad valorum tax rate.

A second equation multiplies the rate times the total gas and diesel fuel consumption to project annual revenues from the ad valorum tax:

$$\text{IF}(M.\text{GE}.13)\text{VBUCKS}(M) = \text{VRATE}(M)*(\text{TGC}(M)*(1.0E3)) \quad (17)$$

in which TGC is the total gasoline consumption; M is the year, with 1967 = 1; and VBUCKS is the annual revenue from the ad valorum tax. The last term is used to convert the estimate into an appropriate form for output.

Showing the impact of the tax on consumer prices also required the addition of two equations. The first showed the impact of the initial imposition of the tax:

$$\text{IF}(I.\text{EQ}.13)\text{CPIGC}(I) = \text{CPIGC}(I)*1.04 \quad (18)$$

The second equation takes the annual increase in gas prices, which has been projected exogenously for the model (OVRRDE(4)), and multiplies it by the ad valorum tax factor of 4%:

$$IF(I.GT.13)CPIGC(I) = CPIGC(I - 1)*(1. + (OVRRDE(4)*1.04) \quad . \quad . \quad . \quad . \quad (19)$$

in which OVRRDE(4) is the annual % increase in CPIGC; and I is the year, with 1967 = 1.

Results

The outputs of the Ad Valorum Tax scenario are shown in Table 8. The table shows the net yield of tax revenues from imposition of the 4% ad valorum tax. As was the case for the graduated increase scenario, the imposition of new taxes results in a small decrease in the consumption of gasoline. This, in turn, results in decreased revenues from the regular fuel sales tax. However, the magnitude of the revenue loss is dwarfed by the new revenue gains, which should reach 195,000,000 by 1990.

TABLE 8.—Revenues from 4% Ad Valorum Motor Fuel Tax (All Revenue Figures are in Millions of Dollars)

Year (1)	Ad valorum tax revenues (2)	Reduced revenues from per gallon fuel sales tax (3)	Additional net revenues (4)	Annual % increase (5)
1981	89.8	3.4	86.4	—
1982	101.4	3.5	97.9	4.77
1983	109.6	3.6	106.0	3.08
1984	118.5	3.7	114.8	3.25
1985	128.3	3.8	124.5	3.43
1986	139.5	4.0	135.5	4.03
1987	152.6	4.1	148.5	4.74
1988	166.6	4.3	162.3	4.62
1989	181.9	.4	181.5	4.72
1990	195.2	.4	194.8	3.00

A comparison of Tables 6 and 8 shows that, although the ad valorum tax produces less revenue than a 4-cent increase in the per gallon tax in the earlier years, by 1990 the total amount of revenue produced is larger with the ad valorum tax. This is because the ad valorum tax, unlike the penny per gallon tax, increases with the price of gas.

However, the last column in Table 8 shows that the annual increase in revenues from the two taxes combined is only 3%–5% per year. This is because, as the ad valorum tax increases, the penny per gallon tax does not. This net rate of increase is not likely to keep pace with highway expenses. With the overall rate of inflation currently exceeding 10%, the real revenues from this scenario would decrease with time.

Scenario E—Fuel Tax Rate Tied to Price Index.—The tax scheme explored in this scenario addresses one of the fundamental problems seen in the ad valorum tax. The addition of a percentage tax without any changes in the taxing procedure for the present 9-cent per gallon tax is not likely to produce an annual increase in revenue that will keep up with inflation.

A possible solution to this problem is a gas tax rate that is in its entirety dependent on some indicator of costs. The index could be one for gas prices, construction costs, overall prices, or a number of other indicators.

How It Works

Under an indexing scheme, the tax rate goes up automatically as the chosen index goes up. For instance, if the gas tax were pegged to the Overall Cost of Living Index (CPIOC), a 20% measured increase in the cost of living would result in a 20% increase in the gas tax per gallon.

The use of some aggregated national or regional price index has a considerable advantage over a tax based on retail price in that it is easy to measure and administer. The tax can be levied at the wholesale level, as the present tax is. This makes it possible to monitor prices, enforce rules, and collect taxes without a large and complex bureaucracy.

Another issue avoided by keeping the tax at the wholesale level is that of equity between fuels at different prices. A retail percentage tax would create tax differentials between different grades of fuel and between different brands of gas, based on the price. This would be difficult to justify.

Possible Indices

One study of indexing options conducted in Alabama (10) concluded that indices based on national data, as opposed to state or local economic conditions, should be used to gage state motor fuel tax levels. The advantages of the national indicators include their greater completeness and reliability and the absence of local short-term price fluctuations that would only serve to produce administrative headaches. The study also argued that the regional components of the U.S. economy are sufficiently interconnected so that most major forces felt at the national level would have local impacts.

The simplest indexing scheme would make changes in the gas tax dependent on the price index for gasoline. This would, in effect, be identical to an ad valorum tax applied at the wholesale level. The tax would increase proportionately to the price of gasoline. The potential problems of such a scheme have already been mentioned. In addition to the possible impact of politically based price fluctuations on tax revenues, such a scheme might be neutralized by a federal price control on gasoline. Such a price ceiling would result in a static tax rate.

Other possible tax indices include the overall consumer price index (CPIOC), a construction cost index, or a locally produced special index of all the features that go into the state transportation expenses. Although the last alternative mentioned might be the most accurate in measuring revenue needs, it would require the most expense and effort by the state. If the index were based on expense records, it would also tend to encourage overspending by state agencies, by adjusting the revenue flow according to expenditures. Such an index of agency expenses, if based on cost data from outside the affected agencies, would require periodic adjustment as the "service mix" of the state transportation program changed. For instance, if the Virginia Highway and Transportation Department were to begin large-scale funding of mass transit programs, the mix of relevant cost factors would be different than for highway programs.

Gas Tax Indexing in Other States

Some variant on the indexing scheme for gasoline taxes is used in the states of Texas, Washington, and New Mexico. However, no state has adapted a law that bases the tax rate solely on cost indices.

The State of Washington has a variable tax based on the weighted average retail price of fuel. The index, which is adjusted every six months, has been in effect since 1977. There is a further provision of the law which fixes a floor for the tax at 9 cents per gallon and a ceiling at 12 cents per gallon. Tax revenues are further required to be within a fixed margin of highway program expenses. This figure is based on the 1973 highway program expenditures plus a 6% annual increase. Thus, not only is the index subject to severe limits, but it is allowed to work only if the resulting revenue flow corresponds faithfully to historic funding needs.

The Washington indexing scheme became dysfunctional in February of 1979, when, as gas prices soared, the index was pinned at the upper limit of 12 cents of tax per gallon. Indications are that it will remain at that level at least until the 1981 legislative session (11).

Texas adopted an indexing plan in 1978. Instead of using a given economic index, the Texas plan authorizes a Highway Cost Index Committee, consisting of the governor, the lieutenant governor, and a comptroller, to establish their own index. The index is a weighted combination of the costs of highway operations, maintenance, and construction. This index is not used to set a tax rate, but to set a highway program revenue base. To the extent that the fixed fuels tax and other transportation user fees fall short of this base, the shortfall is made up out of general revenues (10). New Mexico also adopted an indexing scheme in 1979.

An Indexing Scenario for Virginia.—To demonstrate how an indexing scheme might work for Virginia, a gas tax pegged to the Consumer Price Index for Gasoline Costs, a component of the Bureau of Labor Statistics' Consumer Price Index was investigated. Since the Virginia DMV model assumes a steady, moderate growth rate for gasoline prices, this factor will be useful for showing how a gas cost index would work in an economy with relatively stable fuel prices.

The revenues that would result from indexed gas tax would not necessarily depend only on the index that was used, but the initial rate that the index was set at. It is assumed in this scenario that the index will be set at a level that would allow for the same ratio of tax to gas prices that existed in 1978.

Modification of Model

The Virginia DMV Tax Revenue Model normally sets the tax rate for gasoline according to data fed into the model. To change this characteristic, an indexing equation was added to the model:

$$\text{IF}(I.GE.12)\text{RATE}(I) = (\text{CPIGC}(I-1)*.01*.332) - \text{RATE}(I-1)*.145 \quad (20)$$

in which RATE is the gas tax rate; and .145 is the 1978 ratio of the tax to the gas price.

The RATE for the year is subtracted out so that the tax rate is not included

when one is gaging costs for purposes of taxation. Otherwise, the tax rate would feed on itself, causing a precipitous tax spiral.

The total revenues projected in this scenario are shown in Table 9. Note that the yield is even larger in the "graduated increase" scenario presented earlier. The total revenues collected for the 10-year period are $4,406,000,000, a 45% increase from the base case scenario, and a 8.5% increase over the "graduated increase" scenario.

Since the 6.4% annual increase in the price of gasoline that is assumed in the model is extremely conservative, it is likely that the yield from a gas tax indexed to gas prices would be even larger than the figures projected here. A more moderate increase in revenue could be expected from an index that increases at a slower rate, such as the Consumer Price Index for All Goods (CPIOC).

TABLE 9.—Comparison of Motor Fuel Sales Tax Revenues under Indexing Scenario and under Base Case (All Revenue Figures are in Millions of Dollars)

Year (1)	Revenues under base case (tax-9¢) (2)	Tax under indexing scenario (in cents) (3)	Revenues under indexing scenario (4)	Net difference (5)
1981	281.33	9.6	300.6	19.3
1982	287.40	10.2	326.3	38.9
1983	291.19	10.9	351.8	60.6
1984	295.26	11.6	379.5	87.2
1985	299.67	12.3	409.9	110.2
1986	305.65	13.1	444.8	139.1
1987	313.65	13.9	485.6	171.9
1988	321.14	14.8	529.1	208.0
1989	324.72	15.8	569.2	244.5
1990	326.64	16.8	609.2	282.6

Diesel Fuel Tax.—Among the options available for altering Virginia's transportation tax structure are possible changes in the sales tax for diesel fuel. Through June, 1980, diesel fuel had been taxed at the same rate as gasoline; 9 cents per gallon of fuel sold at the wholesale level.

Current arguments for a change in this tax level take two directions. Some analysis would create a lower tax on diesel fuel as an incentive for reducing overall petroleum consumption by increasing use of diesel fuel. This rationale stems from the fact that most current diesel autos are given a higher mileage per gallon rating than comparably sized and equipped gasoline burning autos. The argument assumes that the savings in mileage would more than balance the likely increase in vehicle use that would result from a tax decrease. Analyses of the long-term impact of increased diesel auto use on overall petroleum consumption have not been encouraging. A study published in the Automotive News (12) projected that, under optimistic assumptions, only a 4% reduction in overall petroleum use would be expected nationwide from a conversion of

40% of the auto fleet to diesel. Any tax incentive would result in an impact of a fraction of that amount.

Others would argue that, if the gasoline sales tax is viewed as a use tax, diesel auto users are already getting a break. Because diesel autos get more miles per gallon, by paying the same tax per gallon of gasoline, diesel buyers are in effect paying less tax per mile of road use.

For this reason, many analysts would favor a higher tax for diesel fuel. Such a discriminatory tax on diesel fuel is currently in effect in five states, with tax differentials varying between 1 and 2 cents (21).

Potential Problems

Because the tax could be administered at the wholesale level through the same mechanisms that are now used to administer the gas tax, the differential diesel tax would be relatively inexpensive and uncomplicated to administer. However, some important technical and equity questions mar the attractiveness of this option.

Setting Tax at Equitable Level.—Efficiencies vary among both diesel and gasoline-powered automobiles. There is currently no consistent information base on which to set a ratio of mileage per gallon for diesel vehicles as compared to gasoline vehicles. Estimates of this ratio vary between 25% and 100% (10). The ratio is likely to vary even more between autos and trucks. Furthermore, with automotive technology evolving at a rapid pace, it is likely that, even if the relationship were quantified, it would be likely to change. Consequently, to maintain its relationship to road use, the tax differential would require periodic adjustment.

Equity With Fuel Efficient Gasoline Powered Autos.—If a tax incentive is given to fuel efficient diesel autos, it can be argued that fuel efficient gasoline powered autos should be given equal treatment. This would necessitate a tax discount on the sale of gasoline to drivers of high-efficiency, gas-powered autos. This scheme would be expensive and cumbersome to administer since it would necessarily be administered at the retail level.

Environmental Impact.—There is considerable doubt about the ability of the diesel powered auto to meet some air emissions standards. Until this issue is resolved, any subsidy for the diesel will be subject to considerable public question.

Impact of Diesel Tax Differentials on Revenues.—A discount or increase in gasoline taxes for diesel fuel would affect DMV revenues in two ways: The revenues per gallon would increase or decrease, and, assuming that the change in the price of diesel fuel to the wholesaler was passed on to the retail customer, the tax differential would act to change the consuming behavior of the public with regard to both diesel fuel and gasoline. This impact on demand for fuels can, in turn, be separated into two components, absolute change in total number of miles traveled, and transfer of vehicle use between diesel and gasoline vehicles.

Using the DMV Revenue Model to Estimate Revenue Impacts.—There is within the model a separate submodel for measuring and projecting diesel fuel consumption separately from gasoline consumption. This makes it possible, as a first step, to measure how much revenues would increase assuming that the tax differential would not alter consuming patterns.

Predicting the effects of the price changes on consumption is more complicated. There is no separate price index within the model for diesel fuel. Besides the impact of a few cents' price change being shown in the previous scenario to be small, it was decided that the change in consumption of diesel fuel due to differential tax treatment would not be calculated. The following scenarios estimate the difference in revenues resulting from differential taxation of diesel fuel assuming that the tax differential will have no effect on consumption. As a result, these estimates of changes in revenue with tax changes are likely to be high but only by a few percentage points.

Results of Diesel Tax Differential Scenarios

Two possible variations in tax policy for diesel fuels were used to develop separate scenarios. These scenarios assumed changes in the tax on diesel fuel from the 9-cent per gallon tax to 7 or 11 cents per gallon. In both cases, the tax on gasoline was assumed to remain unchanged. The results are shown in Tables 10 and 11.

It is clear from these scenarios that, as consumption of diesel fuel increases over the years, its importance as a producer of revenues will increase greatly. However, in no single year will the increase or decrease of the diesel tax by 2 cents result in a change in DMV revenues of more than $16,000,000. The quantity of diesel fuel projected to be sold between 1980 and 1990 is such a small proportion of the total fuel sold that minor incentives or disincentives for diesel fuel use would not have a major effect on the cash flow of the DMV.

Sales Tax.—The sales and use tax on automobiles and other vehicles is another important source of revenue to the DMV. Table 12 shows the levels of tax revenue from this source projected by the DMV revenue model under the present 2% vehicle sales tax through 1990. The sales tax will constitute an increasing share of revenues over this period, growing from 18.6%–32.92% of DMV revenues from the three major revenue sources. This projection assumes that the gasoline sales tax and the vehicle registration fees remain at their present level through 1990. Because the sales tax is a percent tax instead of a fixed tax, it grows in value with the price of the vehicles over time. This explains its increasing dominance.

Policy Considerations.—It may seem unusual that the sales tax on vehicles is only 2%, while the sales tax levied on most other goods in Virginia is 4%. The fact is, the state only receives 2% in tax on the sale of most goods in Virginia. The other 2% consists of a 1% mandatory sales tax, which is turned over to localities, and another 1% optional local sales tax, which is used in virtually all Virginia localities. So, the state only receives 2%, and the localities receive the other 2%.

An argument can be made that the situation concerning the vehicle tax justifies taxation at a higher level to achieve equity with the nonvehicle sales tax. Since more than half the revenues for road construction or a total of $32,407,000 in 1977 are returned to the localities (13), it can be said that the state now receives only a portion of the 2% tax, and the localities receive the rest. This tends to help justify a call for an increased sales tax on vehicles.

Another factor that makes the sales tax look like an attractive target for

a tax increase is its relative inconspicuousness. When an auto is purchased, the tax is usually incorporated into the financing charges. The consumer is often not aware the tax is levied. If he is, it is only levied as often as the consumer purchases a vehicle. This compares favorably with the gas tax, which is brought to the motorist's attention every time he goes to buy fuel, and the

TABLE 10.—Revenue Loss from a 7-cent Diesel Fuel Tax (All Revenue Figures are in Millions of Dollars)

Year (1)	Diesel fuel tax revenues with tax @ 9¢ (2)	Diesel fuel tax revenues with tax @ 7¢ (3)	Net difference (4)
1981	33.64	26.16	7.48
1982	36.15	28.12	8.03
1983	38.96	30.30	8.66
1984	42.11	32.75	9.36
1985	50.89	39.58	11.31
1986	49.57	38.55	11.02
1987	53.99	41.99	12.00
1988	58.95	45.85	13.10
1989	64.52	50.18	14.34
1990	70.80	55.07	15.73

TABLE 11.—Revenue Gain From an 11-cent Diesel Fuel Tax (All Revenue Figures are in Millions of Dollars)

Year (1)	Diesel fuel tax revenues with tax @ 9¢ (2)	Diesel fuel tax revenues with tax @ 11¢ (3)	Net difference (4)
1981	33.64	41.12	7.48
1982	36.15	44.18	8.03
1983	38.96	47.62	8.66
1984	42.11	51.47	9.36
1985	50.89	62.20	11.31
1986	49.57	60.59	11.02
1987	53.99	65.99	12.00
1988	58.95	72.05	13.10
1989	64.52	78.86	14.34
1990	70.80	86.53	15.73

registration fee, which is paid annually. In the following section, the potential revenue impact of a sales tax increase is explored.

Impact of Increased Sales Tax.—In modeling an increased sales tax, it was decided that a realistic scenario would involve a two-stage increase in the tax from 2%–2.5% to 3% over a period of three years. The results of this scenario

are shown in Table 13. Although the increase would only net an additional $22,050,000 in revenue in 1981, the increase in revenue would amount to $102,530,000 in 1990. The 1990 figure would amount to a 16.46-cent increase in total revenues from the three major sources. This increased impact in the later years is due both to the staged increase and to the increasing value of vehicles. Clearly, an increase in sales taxes is a potentially significant source of additional revenues.

TABLE 12.—Projected Sales Tax Revenues with Sales Tax at 2 Percent

Year (1)	Sales tax revenues[a] (2)	Total revenues[a] (3)	% of revenues from sales tax[a] (4)
1980	80.75	434.90	18.60
1981	88.21	449.66	19.60
1982	96.41	465.14	20.73
1983	105.44	479.20	22.00
1984	115.40	494.53	23.34
1985	126.43	511.32	24.73
1986	138.89	530.86	26.16
1987	152.77	553.88	27.58
1988	168.22	578.02	29.10
1989	185.61	600.23	30.92
1990	205.05	622.93	32.92
Total	1,463.16[b]	5,720.67	25.58

[a]In millions of dollars.
[b]Columns may not add to totals due to rounding error.

TABLE 13.—Projected Increase in Sales Tax Revenues with Increased Tax Rate

Year (1)	Rate (2)	Sales tax revenues[a] (3)	Net increase over 2% tax rate[a] (4)
1980	.020	80.74	0.00
1981	.025	110.26	22.05
1982	.025	120.51	24.10
1983	.030	158.15	52.72
1984	.030	173.11	57.70
1985	.030	189.65	63.22
1986	.030	208.33	69.44
1987	.030	229.15	76.38
1988	.030	252.33	84.11
1989	.030	278.41	92.80
1990	.030	307.58	102.53
Total		2,108.22[b]	645.05[b]

[a]In millions of dollars.
[b]Columns may not add to totals due to rounding error.

This projection was run assuming that the increased price of the auto, including taxes, would have no effect on the demand for autos. There are two justifications for this assumption. First, as has already been mentioned, the sales tax is usually "hidden" in the financing charges for autos. Since the buyer does not directly pay the fee, it is not as likely to inhibit the purchaser as it would if it was included in the sticker price. Second, when a $70 fee is considered in the purchase of a $7,000 vehicle, i.e., the magnitude of a 1% sales tax increase, the magnitude of the burden is so small relative to the purchase price, that it is not likely to constitute a major consideration.

These considerations are likely to be valid only for small increases in the sales tax. If the sales tax were to be increased by a very large amount, it

TABLE 14.—Revenue Increases with $20 Auto Registration Fee

Year (1)	Auto registration revenues[a] (Fee-$15) (2)	Additional revenues[a] (Fee = $20) (3)	% increase (4)
1980	46.01	15.34	3.66
1981	46.50	15.53	3.58
1982	47.17	15.73	3.49
1983	47.76	15.92	3.42
1984	48.36	16.12	3.35
1985	48.98	16.33	3.28
1986	49.44	16.48	3.18
1987	49.89	16.64	3.06
1988	50.35	16.78	2.95
1989	50.81	16.94	2.87
1990	51.29	17.10	2.74
Total	536.66[b]	178.88[b]	3.19[b]

[a]Millions of dollars.
[b]Columns may not add to totals due to rounding error.

might become a major consideration in purchasing an auto. Such is the case in some countries where there is a 100% luxury tax on autos.

Registration Fees.—The final element of the tax structure that will be considered here is the annual registration fee paid on all vehicles. The magnitudes of this fee for all vehicles have already been shown in Table 2. The significance of registration fees in terms of DMV revenues has been declining steadily for many years. While the fees have remained at the same level, virtually every relevant cost index has doubled or tripled. A major problem with registration fees is that they are a highly conspicuous form of taxation. Since every vehicle owner must pay them on an annual basis, an increase in these fees is likely to cause considerable public animosity.

Revenue Impact of Increased Auto Registration Fees.—The first scenario considered here involves an increase only in the registration fee for automobiles. The scenario increases the auto registration fee from $15–$20. The results of this experiment are shown in Table 14. During the 11-year period, additional

revenues of $178,880,000 could be realized by the DMV from an auto registration fee increase of $5.

Revenue Impact of Increasing All Registration Fees.—One possible alternative to the scheme shown above is to increase registration fees not only for autos, but also for buses, trucks, motorcycles, and trailers. To test the impact of this policy on revenues, another scenario was tested with the DMV Revenue Model. This scenario involves increases of all registration fees by one-third. This is the equivalent of the increase in auto registration fees from only $15–$20 for all vehicles. The new fee schedule is shown in Table 15.

TABLE 15.—Fee Schedule with All Registration Fees Increased by One-third

Autos	$20.00
Buses	$10.67
Trucks	$66.67
Motorcycles	$9.60
Trailers	$16.67

TABLE 16.—Registration Revenues with All Registration Fees Increased by One-third

Year (1)	Registration revenues[a] (2)	Increase in registration revenues[a] (3)	Percent increase (4)
1980	105.23	26.31	6.48
1981	106.81	26.70	6.37
1982	108.44	27.11	6.26
1983	111.10	27.78	6.18
1984	111.81	27.95	6.09
1985	113.63	28.41	6.01
1986	115.09	28.77	5.87
1987	116.61	29.15	5.71
1988	118.20	29.55	5.56
1989	119.86	29.97	5.40
1990	121.63	30.41	5.28
Total	1,247.41[b]	338.16[b]	5.88

[a]Millions of dollars.
[b]Columns may not add to totals due to rounding error.

Table 16 shows the results of this scenario. A comparison of Tables 14 and 16 shows that the net increase in revenues under this scenario is 5.88%, compared to 3.19% if only the auto registration fee is raised by one-third. This means that 54.25% of the additional revenue that could be achieved by raising all the fees could be accomplished by raising the auto registration fee only.

When considering these results, it is important to remember that the truck fee used in the DMV Revenue Model is only a mean approximation for the more complex system of weight related fees for trucks that is levied by the DMV. Thus, the one-third increase in the fee shown here would be the equivalent of a one-third increase in the fees for all weight classes.

Acknowledgment

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THE 400-LB/HP TRUCK ON GRADES: A NUMERICAL APPROACH

By Hyman A. Todres,[1] M. ASCE

(Reviewed by the Highway Division)

INTRODUCTION

In order to assess the effects of trucks on highway capacity, it is necessary to know the performance of a standard vehicle. Several such vehicles have been proposed. The Highway Capacity Manual (2) gives performance graphs for trucks of 200 lb/hp (120 kg/kW) and 325 lb/hp (195 kg/kW) on a variety of grades, while the American Association of State Highway and Transportation Officials, AASHTO, Policy on Geometric Design of Rural Highways (1) gives a similar graph for the 400 lb/hp (240 kg/kW) truck. As has been pointed out previously (3), the information contained in the graphs is of great value but in a form that is difficult to use in many practical applications.

Clearly a numerical form would be desirable to enable computerized studies to be performed. Consequently Todres and Harris (3) developed a set of equations to approximate the 200 lb/hp (120 kg/kW) curves. For the sake of completeness, a set of equations has been developed for the 400 lb/hp truck and is presented here.

Method of Developing Approximating Equations.—The method consists of replotting the curves on a variety of semilogarithmic and logarithmic papers and finding satisfactory straight-line relationships. It is then necessary to find a relationship between the slopes of those lines and the gradients so that a general set of equations can be written. The details of the method are outlined in the following sections.

In making the approximations, a discrepancy of 3 mph (5 km/h) between graph and equation values has been considered acceptable and has been achieved for all points.

Limiting Speed on Grade.—By means of a log-log plot, it is found that the limiting or crawl speed on grade can be given by the equation:

$$\log v_l = 1.54 - 0.82 \log g \quad \ldots \quad (1a)$$

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in which v_l = limiting speed (mph) and g = grade in percent. Or, using SI units:

$$\log V_l = 1.74 - 0.82 \log g \quad \ldots \quad (1b)$$

in which V_l = limiting speed (km/h). However, the maximum speed under any circumstances is 47 mph (75 km/h), equivalent to the limiting speed on a grade of 0.69%. Thus any grade less than 0.69% should be reset to 0.69% for purposes of computing v_l or V_l.

Deceleration on Grade.—Deceleration occurs on upgrades where the initial speed is greater than the limiting speed.

Replotting the deceleration curves onto semi-log paper gives a series of reasonable straight line approximations of the form:

$$\log v_f = \log v_i - cd \quad \ldots \quad (2a)$$

in which v_i = initial speed on section (mph), v_f = final speed on section (mph), d = length of section (ft) and c = slope of line, which is related to g. Or, using SI units:

$$\log V_f = \log V_i - CD \quad \ldots \quad (2b)$$

in which V_i = initial speed on section (km/h), V_f = final speed on section (km/h), D = length of section (m) and C = slope of line, which is related to g.

The next task is to find the relationship between c and g or C and g. A log-log plot gives the relationship:

$$\log c = 1.524 \log g - 4.733 \quad \ldots \quad (3a)$$

$$\text{Or} \quad \log C = 1.524 \log g - 4.217 \quad \ldots \quad (3b)$$

Thus, the expression for deceleration on grade is generalized to:

$$\log v_f = \log v_i - d\,[10^{(1.524 \log g - 4.733)}] \quad \ldots \quad (4a)$$

$$\text{Or} \quad \log V_f = \log V_i - 3.05\,D\,[10^{(1.524 \log g - 4.217)}] \quad \ldots \quad (4b)$$

Equation (4) gives generally acceptable predictions. However, it fails to meet the permissible 3 mph (5 km/h) discrepancy over sections of the graphs for grades of 4% and steeper.

An alternative approach is to approximate the deceleration curves by straight lines running from the initial speed of 47 mph (75 km/h) to the limiting speed value. The general form of the resulting expression is

$$v_f = v_i - sd \quad \ldots \quad (5a)$$

$$\text{Or} \quad V_f = V_i - SD \quad \ldots \quad (5b)$$

in which s (or S) is the slope of the line and depends on the grade.

The values of s (or S) are determined from the straight line fits and an attempt made to find the relationship between s (or S) and g. Using a log-log plot a near perfect straight line is obtained giving the expression:

$$\log s = 1.407 \log g - 2.714 \quad \ldots \quad (6a)$$

$$\text{Or} \quad \log S = 1.407 \log g - 2.020 \quad \ldots \quad (6b)$$

and, thus:

$$v_f = v_i - d\,[10^{(1.407 \log g - 2.714)}] \quad \ldots \quad (7a)$$

Or $V_f = V_i - D\,[10^{(1.407 \log g - 2.020)}]$ . . . . . (7b)

The use of Eqs. 7*a* or 7*b* instead of 4*a* or 4*b* leads to significantly better fits with maximum discrepancies of 2 mph (3 km/h) at most and usually much better.

The only disadvantage is an aesthetic one in that an abrupt change between deceleration and limiting speed is implied, whereas the logarithmic form does give a smooth exponential decay of speed virtually right down to the limiting speed. This disadvantage is of little consequence when considered against the greatly improved accuracy of fit.

It will be noticed that Eqs. 7*a* or 7*b* cannot be evaluated for zero grade. Should a zero grade occur, its value should be reset to some small positive value (say 0.001) to prevent a computer error message.

Acceleration on Grade.—Should the initial speed on a section be below the limiting speed, acceleration will occur.

A replot of the acceleration curves as speed versus log distance shows a series of straight lines radiating from the point (11 mph, 100 ft) or (17.6 km/h, 30.5 m). The slope h or H of each line is given by

$$h = \frac{\Delta v}{\log \frac{d_2}{d_1}} \quad \text{. . . . . (8a)}$$

$$\text{Or} \quad H = \frac{\Delta V}{\log \frac{D_2}{D_1}} \quad \text{. . . . . (8b)}$$

Plotting the various values of h or H against g on linear graph paper gives the relationship

$$h = 15.75 - 3.96\,g \quad \text{. . . . . (9a)}$$

$$\text{Or} \quad H = 25.20 - 6.34\,g \quad \text{. . . . . (9b)}$$

Thus acceleration can be obtained by means of the two following equations:

$$\log d_x = 2 + \left(\frac{v_i - 11}{h}\right) \quad \text{. . . . . (10a)}$$

(in which d_x = distance in feet which would be required to accelerate from 11 mph to v_i), and:

$$v_f = 11 + h \log \left(\frac{d_x + d}{100}\right) \quad \text{. . . . . (11a)}$$

$$\text{Or} \quad \log D_x = 1.484 + \left(\frac{V_i - 17.6}{H}\right) \quad \text{. . . . . (10b)}$$

(in which D_x = distance in meters which would be required to accelerate from 17.6 km/h to V_i), and

$$V_f = 17.6 + H \log \left(\frac{D_x + D}{30.5}\right) \quad \text{. . . . . (11b)}$$

Use of the Equations.—The equations are readily used in a computer program to determine the speed profile along a grade line.

When using the equations, it must be realized that the speed computed for the end of a section must be compared with the boundary values set by v_t and 47 mph (75 km/h). Should the computed speed fall below v_t, it must be replaced by v_t. Likewise, should the computed speed fall above 47 mph (75 km/h) it must be replaced by 47 mph (75 km/h). v_t = 47 mph (75 km/h) for all grades less than 0.69%; thus, for such grades, reset g to 0.69% for purposes only on computing v_t, or simply set v_t = 47 mph (75 km/h) when g is less than 0.69%.

Accelerations are computed from one set of equations for the entire range of positive, negative, and zero grades. However, some caution is needed here as Eqs. 11*a* or 11*b* can only handle accelerations for grades less steep than 3.98%. This problem can readily be overcome as it is evident from the curves that for grades of 4% and steeper the speed is at limiting speed and is reached essentially instantaneously. Thus, for grades steeper than 3.98% and where the initial speed is less than limiting speed, the final speed can be set automatically to the limiting speed value for any practical section length.

Comments

The equations facilitate the use of computers to generate the speed profile along a given grade line. A program for the HP-34C calculator has been written in which the necessary inputs are the required distance interval, the initial speed, and the grade along the section. Alternatively, elevations can be input and the grade computed. The final speed is displayed and used as the initial speed on the following section. The time required is between 6 and 7 sec per section.

The availability of equations for the 200 and 400 lb/hp (120 and 240 kg/kW) trucks should make possible computer programs to determine the effects on capacity and level of service of various traffic make-ups. Such programs could take into account strings of vehicles consisting of passenger cars, light trucks, and heavy trucks and determine the effects of grade on the speed of individual vehicles and the propagation of effect further down the line.

Conclusions

1. The AASHTO curves showing the effect of grade on the performance of the 400 lb/hp (240 kg/kW) truck have been approximated by a set of equations. The approximations result in maximum discrepancies of 3 mph (5 km/h) from the graph values and are therefore adequate for all practical engineering applications.
2. The equations permit the use of programmable calculators or computers to determine the speed profile of the standard vehicle on any given alinement with grades varying between +7% and −7%.
3. The need for crawler lanes is readily shown, and the determination of their locations is simplified, by means of the equations.
4. The greatly improved speed and convenience offered by the use of computers makes practicable the comparison of several alternative alinements with a view to attaining optimum capacity most economically.

5. The availability of the equations for both 400 lb/hp and 200 lb/hp (240 kg/kW and 120 kg/kW) trucks makes possible computer programs, which will be able to assess the effects of various traffic compositions on highway capacity and level of service, and will be able to take into account the propagation of speed variation effects from vehicles along the upgrade on vehicles any distance back.

Appendix I.—References

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Appendix II.—Notation

The following symbols are used in this paper:

C = slope of deceleration plot of log speed versus distance (km/h)/m;
c = slope of deceleration plot of log speed versus distance (mph/ft);
D_x = distance required to accelerate from 17.6 km/h to V_i km/h on upgrade (m);
D = length of section (m);
d = length of section (ft);
d_x = distance required to accelerate from 11 mph to v_i mph on upgrade (ft);
g = grade (percentage);
H = slope of acceleration plot of speed versus log distance (km/h)/m;
h = slope of acceleration plot of speed versus log distance (mph/ft);
S = slope of deceleration plot of speed versus distance (km/h)/m;
s = slope of deceleration plot of speed vs distance (mph/ft);
V_f = final speed on a section (km/h);
V_i = initial speed on a section (km/h);
V_l = limiting or crawl speed on grade (km/h);
v_f = final speed on a section (mph);
v_i = initial speed on a section (mph); and
v_l = limiting or crawl speed on grade (mph).

Airport Catchment Areas and Air Passenger Demand

By O. E. Moore[1] and A. H. Soliman[2]

(Reviewed by the Air Transport Division)

Introduction

In planning for future air transport developments, detailed forecasts of air travel are required to facilitate evaluation of the impacts of various factors on the pattern of air travel demand. The purpose of this study is to build suitable econometric models to explain variation in air travel demand among several area pairs in a given year, in terms of known factors characteristic of each pair. A major concern of the study is the development of suitable demand functions enabling past and present passenger trip profiles to be expressed quantitatively in terms of such variables as populations, indicators of socioeconomic activity, and measures of air service.

Either of two approaches is commonly used in demand model building: derivation using time series analyses on demand variation over time, between individual pairs of cities or areas, or, alternatively, development of a cross-sectional function based on differences in volumes among a number of pairs of cities or areas at a single time. This study also proposes, where applicable, to make use of combined cross-sectional and time series information in an attempt to improve the quality of the conclusions drawn.

The independent variables used in the demand function developed for air travel in the market area were population, incomes, air fares, and empirically derived community-of-interest or attractivity measures. The inclusion of other factors or indices that might further contribute to the demand relationship was prohibited by the lack of consistent records matching the market areas chosen, since most information about important economic indicators is normally recorded at the provincial level. The basic demand function used in this study is consistent with that found to be most satisfactory in other comparable works (1,5). Passenger trips between areas are seen as a function of population, per capita income, air fare, and some community-of-interest measure.

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Market for Air Travel.—In the first modeling phase, 21 market areas are defined (5). Each of these areas includes the immediate environs of a major city. (Fig. 1) No attempt is made to reconcile the extent of these areas with the population directly served by the air facilities they contain. Therefore, trips are also derived from the populace not directly included in these metropolitan areas, but that which resides in nearby zones where there are no facilities for intercity air travel.

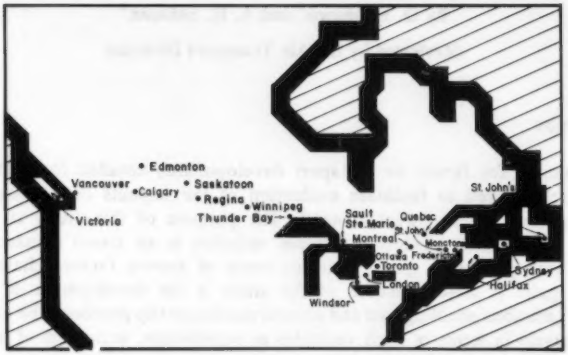

FIG. 1.—Domestic Air Travel Market—Cities

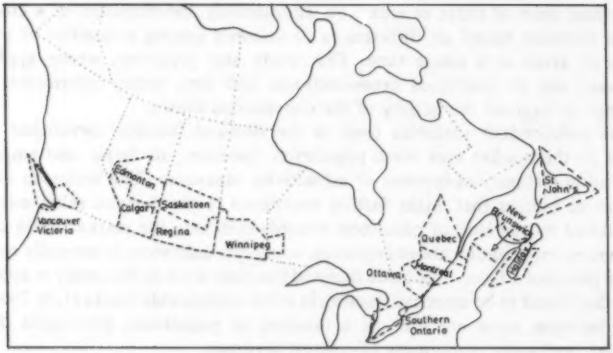

FIG. 2.—Domestic Long-Haul Air Market High-Population Area (1)

The second phase explicitly treats the problem of rationalizing area boundaries. The model is based on 13 areas (Fig. 2), each surrounding a major city or a cluster of cities. These areas were deliberately defined to be catchment areas for the major airports contained within them. The population in each area will make use of these airports, and are unlikely to travel by surface transport to another area prior to commencing an outbound flight. This stipulation must

be satisfied for any demand function relating passenger trips to variables, such as population to be valid. The boundaries must encompass many smaller towns and cities within convenient driving distance of the major airports (including towns possessing their own scheduled connecting services) since substantial numbers of long-haul passengers fly for personal reasons and may minimize the journey cost by avoiding a short connecting flight. Passenger traffic from "feeder" airports in an area is incorporated into the area's total traffic, and airports with scheduled air services contained in each area are listed in Table 1. By far the largest portion of origin and destination passenger trips are generated

TABLE 1.—Airports With Scheduled Service Contained in Long-haul Market Areas

Area (1)	Airports (2)	Area (3)	Airports (4)
St. John's	St. John's	Saskatoon	Saskatoon
	Gander		Prince Albert
			Yorkton
Halifax	Halifax		
	Yarmouth	Regina	Regina
			Swift Current
New Brunswick	Saint John		
	Moncton	Edmonton	Edmonton International
	Fredericton		Edmonton Ind.
	Charlo		Red Deer
	Chatham		
Quebec	Quebec	Calgary	Calgary
	Sagueney		Lethbridge
	Charlevoux		Medicine Hat
Montreal	Dorval	Vancouver-Victoria	Vancouver
	Trois Rivieres		Victoria
			Nanaimo
Ottawa	Ottawa		Port Hardy
			Alert Bay
Southern Ontario	Toronto		Campbell
	Hamilton		River
	Windsor		Port Alberni
	London		Tofino
	Sarnia		
Winnipeg	Winnipeg		
	Brandon		
	Kenora		
	Dryden		
	Dauphin		

by these airports, and, generally, all the area's long-haul traffic passes through them. These market areas are identical to the traffic generation zones adopted in the National Planning for Airports Study (7).

Historic passenger trip interchanges, fares, populations, and per capita incomes for the 21-cities phase are readily available (5) for the period 1960–1971. Demand functions for the above phase and period are also contained in the same source. More recent historic data (up to 1975) have also been compiled at the University of Manitoba.

In the case of the 13 long-haul market areas, only historic passenger trips

and demand models (1960–1970) are readily available (1). Updating data for both phases was carried out as follows.

Passenger trip interchanges were compiled from the Aviation Statistics Centre records of passenger origin and destination trips for domestic city pairs (10). City pair trips are transformed into totals for pairs of areas by summing the trips of all the city pairs within each area pair. Populations for the study areas were determined from census data for 1976 Statistics Canada County and Census Division estimates for 1970–75 and the Financial Post Survey of Markets (6,11,12). Personal disposable income estimates were also obtained from the Financial Post Survey of Markets. Air fares between areas are represented by economy fares as supplied by Air Canada in Winnipeg. Fare data for before 1973 were not available from that source and time constaints made it virtually impossible to obtain them from such sources as Air Canada headquarters in Montreal or the Canadian Transport Commission in Ottawa. However, the information was compiled from old Air Canada schedules obtained from private sources.

Calibration and Analysis of Demand Models

Phase 1: 21 Cities/69 City Pairs.—Observations of passenger trips and the independent variables can be arranged from the data file in two ways (5): (1) By individual city pair, comprising a time-series of 18 sets of observations covering the period 1960–77 (69 series, one for each city-pair); and (2) by year, comprising a cross-sectional series of 69 city-pairs of observations (18 series, one for each year).

The time series technique minimizes the effects of yearly fluctuations and emphasizes trends for each pair. On the other hand, cross-sectional analysis relates all the variables observed in a given year for all the city pairs. It, therefore, highlights yearly demand fluctuations prevailing throughout the study area as a whole.

To be consistent with the findings of previous analyses (5), the following demand model was adopted for the period 1972–77:

$$T_{ijt} = K(P_iP_j)_t^{\alpha} \cdot (I_iI_j)_t^{\beta} \cdot F_{ijt}^{\gamma} \cdot e_{ijt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

or in logarithmic form:

$$\ln T_{ijt} = K_t + \alpha \ln (P_iP_j)_t + \beta \ln (I_iI_j)_t + \gamma \ln F_{ijt} + e'_{ijt}$$

The formulation is an "expanded" gravity model in which a per capita income term is included and distance is replaced by air fare.

A FORTRAN (WATFIV) program was employed, through the computer facilities of the University of Manitoba, to calculate cross products and to effect the necessary logarithmic transformations. The multiple regression program known as BMDPIR, contained in the BMDP statistical package (3), was used for the least squares regression analysis. By combining the two programs, a series of cross-sectional models for the years 1972–77 were developed, in order to derive a set of values for the coefficients α, β, γ and K_t.

The statistics showed a rather poor fit of the model to observations. For the years after 1972, the highest value of R^2, the coefficient of multiple determination, is a meager 0.50, associated with the 1975 cross-sectional model. A plot of residuals against predicted values for the 1975 model is shown in

Fig. 3. In the ideal situation, the residuals should distribute along the zero value, showing no dependence on the estimated values. The apparent curvilinearity in Fig. 3 suggest an inadequate model (2,4,8). Similar unsatisfactory patterns are observed when the residuals are plotted against transformed population and income cross-products.

In Ref. 5, where this difficulty was encountered, an attractivity factor was introduced. The factor is defined for each city pair simply as the average ratio of predicted to observed demand over the period in question, and is an attempt to represent some measure of the "attractivity" between cities for any given city pair.

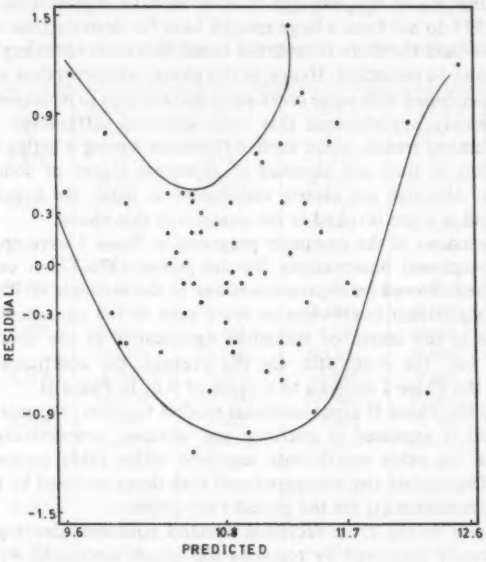

FIG. 3.—1975 Phase I Model: Distribution of Residuals With Predicted Values

For the period 1972–77, the basic "lack of fit," as reflected in the statistics and other factors discussed above, was considerable. Therefore, it was considered unreasonable and undesirable to expect that any attractivity factor should account for so much variation as to make the analysis in this phase worthwhile.

Phase II: Areas/58 Area-Pairs.—In an effort to consider some factors not dealt with in Phase I, particular attention is paid to zoning and competition from other modes (13,14). Thirteen zones or areas are thus deliberately defined to be quite extensive, each describing a logical "catchment area" for the major airports within it. Errors due to modal competition are minimized by considering only those zoned separated by more than one day's drive, i.e., 497 mi. (800 km).

The same independent variables as in Phase I are considered. The 1973 cross-sectional observations were regressed in various formulations to determine the most suitable combination of the available independent variables. The model formulation (Eq. 1) again proved most satisfactory and accordingly is restated as:

$$T_{ijt} = K(P_i P_j)_t^{\alpha} \cdot (I_i I_j)_t^{\beta} \cdot F_{ijt}^{\gamma} \cdot e_{ijt} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (2)$$

All incomes and fares are expressed in terms of 1968 constant dollars in this phase, to facilitate comparison with similar work undertaken by the Canadian Transport Commission for the period 1960–1969 (1).

Once again the data file can be arranged either by individual area pair, for time series analysis or by year, for cross-sectional analysis. The energy crisis years 1973–1977 do not form a large enough base for deriving time-series trends. The larger the base the more reliable the trend, however, revealing that periodic fluctuations may be smoothed. Hence, in this phase, whenever time series analysis is used, it is combined with some cross-sectional analysis to maintain perspective.

It is commonly hypothesized that cross-sectional differences can be used to analyze demand trends, since such differences among a series of area pairs at given points in time are assumed to represent stages of some pattern of development. Although not clearly established as valid, the hypothesis seems reasonable and is often invoked in the analysis in this phase.

Modified versions of the computer programs in Phase I were applied to each set of cross-sectional observations for the period 1970–77. A comparison of results obtained showed an improvement due to the methods of Phase II.

The most significant improvements were seen in the consistently higher R^2 statistics and in the increased statistical significance of the coefficient taken all together, i.e., the F-statistic. On the average, the coefficient R^2 jumped from 0.37 in the Phase I analysis to a value of 0.81 in Phase II.

Comparing the Phase II cross-sectional models together, the intercept K_t and the coefficient β appeared to decrease and increase, respectively, with time. The values of the other coefficients remained within fairly narrow ranges for most years. The models also compared well with those obtained by the Canadian Transport Commission (1) for the period 1960–1969.

The reliability of the cross-sectional demand equations developed in Phase II may be greatly improved by reducing the errors associated with individual area pairs. A single year's observations errors in residuals must be regarded as random variables, provided no autocorrelation exists. The availability of eight sets of observations and errors, one set each for the years 1970–77, ought to permit consistencies in individual area pair errors to be identified.

Firstly, a common base is provided by including the entire eight years' observations in a single regression to derive one demand model. In this model, each of the 58 area pairs has eight values of the error term, one for each year. A close look at them reveals that the eight residual or error values per pair resemble each other, not only in magnitude, but in sign. In addition, they sometimes appear to follow definite trends in time.

Noting the above, it became imperative to investigate whether error observations were significantly related to the area pair or the time to which they belong, or both. The analysis, thus, becomes a typical two-way classification factorial experiment, with one observation per cell, the two factors being area pair and

year. The linear statistical model for the classification may be written as (8)

$$k = 1, 2, \ldots, 58; \quad e_{kt} = \mu + \tau_k + \beta_t + (\tau\beta)_{kt} + \epsilon_{kt}; \quad t = 1, 2, \ldots, 8 \ldots\ldots (3)$$

In the case of one observation per cell (or pair year combination) the two-way classification procedure assumes that the two-factor interaction effect is zero (8). The model (Eq. 3) thus becomes

$$k = 1, 2, \ldots, 58; \quad e_{kt} = \mu + \tau_k + \beta_t + \epsilon_{kt}; \quad t = 1, 2, \ldots, 8 \ldots\ldots\ldots (3a)$$

Using the subprogram ANOVA of the Statistical Package for the Social Sciences (9) computer files at the University of Manitoba, the statistical significance of the area pair and year effects were analyzed. The analysis of variance (ANOVA) confirmed that both effects were indeed highly significant even at the 0.1%

TABLE 2.—Cross-sectional Demand Functions from the Formulation (4.4)

Year t (1)	K_t (2)	α (S.E.) (3)	β (S.E.) (4)	γ (S.E.) (5)	δ (S.E.) (6)	R^2 (S.E.) (7)
1970	5.875	1.207	0.961	−1.875	1.107	0.995
		(0.019)	(0.096)	(0.410)	(0.025)	(0.1305)
1971	4.087	1.075	1.272	−1.794	0.987	0.995
		(9.020)	(0.127)	(0.040)	(0.025)	(0.1257)
1972	4.437	1.179	1.159	−1.803	1.064	0.9732
		(0.044)	(0.304)	(0.100)	(0.060)	(0.2937)
1973	3.460	1.106	1.425	−1.917	0.968	0.9967
		(0.015)	(0.948)	(0.036)	(0.020)	(0.0982)
1974	4.067	1.035	1.358	−1.879	0.948	0.9967
		(0.015)	(0.948)	(0.036)	(0.020)	(0.0982)
1975	4.318	1.006	1.300	−1.819	0.968	0.9956
		(0.017)	(0.114)	(0.040)	(0.022)	(0.1104)
1976	4.278	1.035	1.335	−1.900	0.986	0.9953
		(0.017)	(0.120)	(0.042)	(0.022)	(0.1143)
1977	4.852	1.022	1.178	−1.763	1.012	0.9953
		(0.017)	(0.115)	(0.042)	(0.022)	(0.1142)
1973–1977	4.683	1.045	1.246	−1.859	0.983	0.995
		(0.007)	(0.029)	(0.019)	(0.009)	(0.1155)
1970–1977	4.523	1.084	1.235	−1.845	1.006	0.9908
		(0.008)	(0.029)	(0.020)	(0.011)	(0.1634)

Note: $\text{Ln } T_{ijt} = K_t + \alpha \ln (P_i P_j)_t + \beta \ln (I_i I_j)_t + \gamma \ln F_{ijt} + \delta A_{ijt} + \epsilon_{ijt}$.

significance level. This means that about 97% of what had been regarded as experimental error could now be accounted for in terms of an area-pair effect and effect due to time. Estimates of τ_k and β_t for each of the 58 area pairs and the 8 yrs were developed by the subprogram ANOVA. As was expected, the overall mean of the residuals is zero.

It is possible that the area pair and time effects indicate the existence of some missing independent variable. The constraints of time prevented any investigation in this direction. On the other hand, the area pair effects may be seen as some sort of community-of-interest or attractivity factor, accounting for a variety of factors difficult to quantify. Therefore, values for the St. John's

area are above average, since air service is perhaps the most attractive way to cross the Gulf of St. Lawrence; low Quebec City-to-the-West values reflect language and cultural differences; the agriculture-based economy of Saskatchewan no doubt explains the low values for the areas. The time factor suggests a general decrease in willingness or need to undertake interzonal travel. This may be due to the increasing weight placed on time and perhaps more importantly, to the rapid improvements during the years in communications and data bank systems.

The high statistical significance of the area pair and time effects is strong support for incorporating these effects into the demand function. Therefore, a dummy variable intended to represent the combined effects of area pair and

TABLE 3.—Regression ANOVA Table 1975 Cross-sectional Model—No Dummy Variable

MULTIPLE R	0.9132	STD. ERROR OF EST.		0.6746	
MULTIPLE R-SQUARE	0.8340				
ANALYSIS OF VARIANCE	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO	P(TAIL)
REGRESSION	123.471	3	41.157	90.446	0.00000
RESIDUAL	24.573	54	0.455		
VARIABLE	COEFFICIENT/STD. ERROR		STD. REG COEFF	T	P(2 TAIL)
INTERCEPT	-6.886				
LN(F)	-1.835	0.245	-0.421	-7.496	0.000
LN(XPOP)	0.982	0.102	0.561	8.744	0.000
LN(XIN)	3.026	0.655	0.294	4.621	0.000

TABLE 4.—Regression ANOVA Table 1975 Model with Dummy VAR, LNA (*I,J*)

MULTIPLE	0.9978	STD. ERROR OF EST.		0.1104	
MULTIPLE R-SQUARE	0.9956				
ANALYSIS OF VARIANCE	SUM OF SQUARES	DF	MEAN SQUARE	F RATIO	P(TAIL)
REGRESSION	147.398	4	36.849	3023.745	0.00000
RESIDUAL	0.646	53	0.012		
VARIABLE	COEFFICIENT/STD. ERROR		STD. REG COEFF	T	P(2 TAIL)
INTERCEPT	4.318				
LN(F)	-1.819	0.040	-0.417	-45.415	0.0
LN(XPOP)	1.006	0.017	0.633	59.563	0.0
LN(XIN)	1.300	0.114	0.126	11.401	0.0
LNA(I,J)	0.968	0.022	0.428	44.310	0.0

year, i.e., $\tau_k + \beta_t$, was assigned to each area pair for each year and a modified demand model derived by the least squares multiple regression technique. With the dummy variable the model formulation looks like

$$T_{ijt} = K(P_iP_j)_t^{\alpha} \cdot (I_iI_j)_t^{\beta} \cdot F_{ij}^{\gamma} \cdot e^{\delta A_{ijt}} \cdot \epsilon_{ijt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

in which A_{ijt} = dummy variable for combined area-pair, time effects, δ = coefficient.

The results of the introduction of the dummy variable are shown in Table 2. It appears that all the cross-sectional models now fit the observations almost perfectly; whether this is in fact significant or not must now be investigated.

To establish that the model provides statistically more reliable results than the model without the dummy variable, the earlier results are compared with

those shown in Table 2. Consider the 1975 cross-sectional model typical and suitable as a basis for comparison. The summary statistics associated with the 1975 models derived from the two fits under consideration are displayed in Tables 3 and 4.

Comparing these tables, the remarkable improvement in the statistic R^2 can be seen. However, this statistic should be used with caution, since it is always possible to make R^2 equal unity by simply adding enough terms. For meaningful model improvement, a superior R^2 value should be matched by a sufficiently reduced error or residual sum of squares, i.e., the variation still unaccounted for by the model. Indeed, it is in this respect that the superiority of the model (Eq. 4) stands out. Tables 3 and 4 show that the residual sum of squares has been drastically reduced by Eq. 4 from 24.573–0.646. As a direct result the error mean square value is also slashed from 0.455–0.012, causing the all-important

TABLE 5.—Correlation Matrix—Formulation (4.4)

(1)		LN(*TRIP*) (2)	LN(*F*) (3)	LN(*XPOP*) (4)	LN(*X1N*) (5)	LNA(*I,J*) (6)
LN(*TRIP*)	1	1.0000	—			
LN(*F*)	2	−0.5321	1.000			
LN(*XPOP*)	3	0.7718	−0.1576	1.0000		
LN(*X1N*)	4	0.6015	−0.0773	0.4900	1.0000	
LNA(*I,J*)	5	0.4882	−0.0122	0.0253	0.3101	1.0000

TABLE 6.—Correlation Matrix of Regression Coefficients—Formulation (4.4)

(1)		LN(*F*) (2)	LN(*XPOP*) (3)	LN(*X1N*) (4)	LNA(*I,J*) (5)
LN(*F*)	2	1.0000			
LN(*XPOP*)	3	0.1374	1.0000		
LN(*X1N*)	4	−0.0029	−0.5029	1.0000	
LNA(*I,J*)	5	0.0088	0.1525	−0.3416	1.0000

F ratio to leap from 90.446–3023.745, to establish the high statistical significance of the model.

The other statistics, such as the standard errors of the regression coefficients and of the estimated regression plane, are all greatly reduced to strengthen the virtues of the new model formulation. The standard error of estimate is down to 0.114 from 0.6746, and the fit is unquestionable.

More generally, the introduction of the dummy variable to account for the area pair and year effects has increased the values of K_t. More importantly, the elasticities (β) of the income cross-product are reduced, revealing that the explanatory power of this variable has been cut approximately in half. This fairly large reduction indicates that the dummy variable reflects area pair affluence to some extent. This interpretation is borne out in the correlation matrix associated with the fit of the model as shown in Tables 5 and 6. Table 5 shows that, of all the other independent variables, the dummy variable is most highly correlated

with the transformed incomes cross-product. Note also that all the independent variables are highly correlated with the dependent variable, while their own intercorrelation is quite low. This is very much in keeping with the assumption of the multiple regression technique (2,4,8) and further enhances the adequacy of the model. Table 6 verifies that the elasticities of the income cross-product and dummy variable are in fact inversely correlated to a large degree so that, as one variable increases in its explanatory power, the other can be expected to lose some of its importance.

Conclusions and Suggestions for Further Research

The relative constancy of the elasticities of the coefficients shown for various years in Table 2 suggests that during the period of study, public attitudes toward air travel remained relatively unchanged. It can be inferred from this that one regression model can be derived for the entire study period. The resulting coefficients at the bottom of the table are approximate averages of the coefficients of all years.

The introduction into the analysis of a differentiation between pair effects and year effects offers a method of explaining a greater percentage of trips. Analysis has shown that this technique is statistically valid, and has made a significant improvement in the model.

Further research in this area could begin with the application of the dummy variable to the years before 1970 to further test the overall validity of the model. The use of models of other types, such as time series analysis, should also be explored.

The whole problem of model competition, which was deliberately side-stepped in this research by only using area pairs separated by a given distance, should be explicitly studied. This research would require dealing with more closely spaced area pairs.

Acknowledgments

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Appendix II.—Notation

The following symbols are used in this paper:

e_{ijt} = error in trips estimated between cities i and j in year t;
e'_{ijt} = error in ln trips estimated between cities i and j in year t;
e_{kt} = the residual or error associated with the k^{th} area pair in the year t, is decomposed into;
F_{ijt} = one-way economy air fare between cities i and j in year t (\$1961);
$(I_iI_j)_t$ = per capita personal disposable income cross-product, areas i and j, (based on 1968 constant dollars), in year t;
$(P_iP_j)_t$ = Populations cross-product, areas $i \times 10^{10}$ and $j \times 10^{10}$ in year t;
T_{ijt} = two-way passenger origin and destination trips between areas i and j, in year t;
$\alpha, \beta, \gamma, K_t$ = regression coefficients;
β_t = the effect of time (that portion of the residual derived solely because it is associated with the year t);
ϵ_{kt} = the experimental error associated with the linear statistical model (Eq. 3);
μ = an overall mean value common to all residuals;
τ_k = the effect of the k^{th} area pair (that portion of the residual derived solely because it belongs to the k^{th} pair); and
$(\tau\beta)_{kt}$ = the portion of the residual contributed by the interaction of the two factors pair and year.

BAYESIAN UPDATING OF TRIP GENERATION PARAMETERS

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(Reviewed by the Urban Transportation Division)

INTRODUCTION

Current research in urban transportation planning is actively seeking simplified planning procedures that would minimize the cost of developing a continuing, comprehensive, and coordinated transportation planning process, particularly in small urban areas. The most costly element in the traditional urban transportation planning practice is the full-scale home-interview origin-destination (O-D) survey. In small urban areas the survey typically consists of interviewing between 8–12% of all the households in the study area. An alternative to this costly procedure consists of synthesizing travel patterns using travel forecasting models developed in other similar urban areas where full scale O-D surveys have already been conducted. However, before using models calibrated in an area other than the study area, it might be desirable to modify them in order to reflect local conditions more accurately. This can be done by updating the parameters of the borrowed models using information particular to the area under study. This information can be either objective data based on small scale survey (1) or subjective judgment based on past experience.

This paper presents a methodology based on Bayesian statistics for updating cross-classified household trip generation rates. After reviewing some previous applications of Bayesian updating in transportation, a brief description of the cross-classification approach to trip generation analysis is presented in order to provide better understanding of the context in which the Bayesian updating methodology discussed in this paper is to be applied. This methodology considers the following cases:

1. A small disaggregate sample is collected in the area under study.
2. Consecutive small samples are collected as part of a continuing planning process.

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3. Subjective information, reflecting the feeling of and experience accumulated by experts familiar with the study area, is used to update the trip rates.

Use of Bayesian Updating in Transportation.—Bayesian updating is used when prior information (such as model parameters developed in another urban area) is to be updated using new information (such as results of a small sample from the study area). The updated information is called the posterior information. In terms of probability, Bayes' theorem can be expressed as:

$$\begin{bmatrix}\text{Posterior Probability}\\ \text{of Parameter } \theta,\\ \text{given the sample}\\ \text{outcome}\end{bmatrix} = \begin{bmatrix}\text{Sample}\\ \text{Likelihood,}\\ \text{given } \theta\end{bmatrix} \times \begin{bmatrix}\text{Prior}\\ \text{Probability}\\ \text{of } \theta\end{bmatrix} \div \begin{bmatrix}\text{Marginal}\\ \text{Sample}\\ \text{Likelihood}\end{bmatrix}$$

Formulas and expressions for posterior information parameters have been derived from the basic theorem for application to various general situations (4,9). There are several examples of application of Bayesian methodology in transportation planning.

Isibor (7) suggested Bayesian updating techniques in the context of modeling the impact of highway improvements on the value of adjacent land parcels (7). Sinha (10) showed how Bayesian statistics could be used by planners in making improved decisions regarding population forecasts.

Bayesian approach was also suggested for updating parameters of discrete choice models of travel behavior (1), as well as mode choice information in small urban areas (3). Chan, et. al. (2) applied Bayesian methodology to update travel demand elasticities. These applications demonstrate the flexibility and potential of Bayesian updating technique in transportation planning.

Cross-Classification Approach to Trip Generation Analysis

The cross-classification technique for household trip generation analysis stratifies household trip rates according to the major household socio-economic characteristics affecting trip making behavior, such as auto ownership, household size, and income. Households are grouped according to these characteristics, and average daily trip rates for each of the household socio-economic categories (or cells) are then developed. In order to do so, trip rates (by trip purpose) for the individual households are computed and accumulated within each cell. The average number of trips made by households as well as the standard deviation are then computed for each household socio-economic group. Additional details on this technique can be found in the appropriate references (5,6). The cross-classified rates for home-based work trips produced by households in Greater Lafayette, Indiana, are reproduced in Table 1 (8). The following information is shown for each cell: the average trip rate for households in the cell, the number of sampled households in that cell, and the standard deviation of the trip rates within the cell.

Cross-classified trip rates have been observed to be stable between similar urban areas (5); this means that these trip rates can be transferred and used in areas similar to the one where they have been developed. However, no two urban areas are identical, and planners would like to be more confident about models that have been calibrated in other localities. Bayesian updating

provides the needed framework for making "borrowed" models more representative of local conditions.

Bayesian Updating of Cross-Classified Trip Generation Rates

In this section, analytical expressions as well as example applications are presented for the following two cases: (1) Updating based on new information obtained from small disaggregate sample combined with the prior information based on the borrowed travel data from a similar urban area; and (2) updating based on new information derived from subjective judgment combined with the prior information based on the borrowed travel data from a similar urban area. This is the prior information. After processing the small sample, updating is done on a cell by cell basis, whereby the trip rate for each socio-economic combination (cell) is updated combining the borrowed rate with the sample

TABLE 1.—Cross-Classification of HBW Vehicle Trip Rates: Lafayette, Indiana

Autos per household (1)		Household Size: Families of one (2)	Families of two (3)	Families of three (4)	Families of four (5)	Families of five or more (6)
None	θ_{ij}	0.004	0.004	0.091	—	—
	n_{ij}	463	480	22	—	—
	S_{ij}	0.093	0.064	0.426	—	—
One		0.572	0.868	1.118	1.371	1.456
		537	771	271	224	171
		1.129	1.30	1.339	1.507	1.390
Two		0.867	1.870	2.266	2.280	2.231
		15	453	256	236	290
		1.457	1.809	1.815	1.652	1.667
Three of more		—	2.00	2.704	2.232	2.888
		—	14	54	99	89
		—	2.075	2.376	2.272	2.323

Note: Average household trip rate = θ_{ij}; Number of sampled households in cell = n_{ij}; and Standard Deviation of trip rates in cell = S_{ij} (8).

information from the corresponding cell. It is required that each cell has at least 30 observations in both prior and sample matrices in order to meet the necessary assumptions.

Before the expressions for the updated parameters are presented, a brief description of the statistical procedure is necessary. In this discussion, the following notation will be used.

For the cell being updated in the borrowed or initial trip rate table (prior information), θ_1 = average trip rate; n_1 = number of observations; and S_1^2 = variance of the trip rates.

For the corresponding cell (same socio-economic combination) developed from the small disaggregate sample, θ_s = average trip rate; n_s = number of observations; and S_s^2 = variance of the trip rates.

The average trip rate for a certain cell is the mean of a sample of individual

household trip rates. Regardless of the statistical distribution of trip rates across the population of households (of a given category), the sampling distribution of the mean (i.e., that of the random variable "average trip rate," for that same cell) can be considered to be reasonably normal (by virtue of the Central Limit Theorem). In order for the normality property to hold, we stipulated the above-mentioned requirement that a cell have at least 30 observations.

The prior distribution of the average trip rate for a given cell is the one derived from the borrowed or initial trip table. This distribution is normal with parameters θ_1 and $\sigma_1^2 = S_1^2/n_1$, the unbiased estimators of the mean and variance, respectively. This information is to be updated with the corresponding parameters obtained from a small household sample survey. The sampling distribution of the mean (from the survey) is also normal with parameters θ_s and $\sigma_s^2 = S_s^2/n_s$.

For the situation described above (both prior and sample distributions being normal with variance assumed to be known), the updated (posterior) distribution of the average trip rate has the following parameters:

$$\text{mean,} \quad \theta_2 = \left[\frac{\frac{1}{\sigma_1^2}}{\frac{1}{\sigma_1^2}+\frac{1}{\sigma_s^2}}\right]\theta_1 + \left[\frac{\frac{1}{\sigma_s^2}}{\frac{1}{\sigma_1^2}+\frac{1}{\sigma_s^2}}\right]\theta_s \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

which becomes after substitution

$$\theta_2 = \left[\frac{\frac{n_1}{S_1^2}}{\frac{n_1}{S_1^2}+\frac{n_s}{S_s^2}}\right]\theta_1 + \left[\frac{\frac{n_s}{S_s^2}}{\frac{n_1}{S_1^2}+\frac{n_s}{S_s^2}}\right]\theta_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\text{Standard Deviation,} \quad \sigma_2 = \sqrt{\frac{1}{\frac{1}{\sigma_1^2}+\frac{1}{\sigma_s^2}}} \quad \text{or,} \quad \sigma_2 = \sqrt{\frac{S_1^2 \times S_s^2}{n_1 S_s^2 + n_s S_1^2}} \qquad (3)$$

The resulting posterior distribution (of the average trip rates) is also normal, with mean θ_2 and standard deviation σ_2. It should be reemphasized that this distribution is not that of the individual household trip rates (corresponding to the cell under consideration), but that of the average trip rates for that cell. Moreover, the shape of the distribution of individual household rates is not known. However, both distributions have the same mean (θ_2), but not the same standard deviation.

The above technique can be best understood through a detailed step-by-step example. As a hypothetical example, it can be assumed that the trip rate table for Lafayette's home-based work, HBW, productions is to be used in Bloomington (Lafayette and Bloomington are two small urban areas in Indiana). A small disaggregate sample would be collected in Bloomington that would yield a trip rate table. The process of updating would then take place on a cell by cell basis. Considering the cell corresponding to households of four persons, owning two cars in Table 1, the following computations can be made.

Prior information: $\theta_1 = 2.28$; $n_1 = 236$; and $S_1 = 1.652$.
Sample information (hypothetical): $\theta_s = 2.45$; $n_s = 31$; and $S_s = 1.69$.
Posterior (updated) information:
Using equation 2,

$$\theta_2 = \frac{\dfrac{236}{(1.652)^2}}{\dfrac{236}{(1.652)^2} + \dfrac{31}{(1.69)^2}} \times 2.28 + \frac{\dfrac{31}{(1.69)^2}}{\dfrac{236}{(1.652)^2} + \dfrac{31}{(1.69)^2}} \times 2.45 = 2.30 \quad \ldots\ldots (4)$$

and using equation 3,

$$\sigma_2 = \sqrt{\frac{(1.652)^2 \times (1.69)^2}{236 \times (1.69)^2 + 31 \times (1.652)^2}} = 0.101 \quad \ldots\ldots (5)$$

Successive Updating.—If another sample is collected at a later point in time, either in the same area or in another area for the purpose of further updating the information already available, a slightly different situation is created. The prior information in this case still consists of the sampling mean distribution, and it is still normally distributed. However, its parameters are different, and, therefore, computational formulas 2 and 3 will be different in form, even though they remain unchanged in content. The prior state of knowledge about that distribution at this stage consists of the parameters θ_2 and σ_2 computed in the previous step. Therefore, the prior distribution is a normal distribution with mean θ_2 and variance σ_2^2, which are assumedly known. The new sample distribution will have the same notation as in the previous case (θ_s, n_s, S_s). No prior sample size is needed in order to find the posterior distribution parameters. Let θ_3 and σ_3^2 be the mean and variance, respectively, of the posterior distribution, (which is also normal) and the formulas to compute them are given in ref. 4, as shown below:

$$\text{mean,} \quad \theta_3 = \left[\frac{\dfrac{1}{\sigma_2^2}}{\dfrac{1}{\sigma_2^2} + \dfrac{1}{\sigma_s^2}}\right]\theta_2 + \left[\frac{\dfrac{1}{\sigma_s^2}}{\dfrac{1}{\sigma_2^2} + \dfrac{1}{\sigma_s^2}}\right]\theta_s \quad \ldots\ldots (6)$$

which becomes after substitution:

$$\theta_s = \left[\frac{\dfrac{1}{\sigma_2^2}}{\dfrac{1}{\sigma_2^2} + \dfrac{n_s}{S_s^2}}\right]\theta_2 + \left[\frac{\dfrac{n_s}{S_s^2}}{\dfrac{1}{\sigma_2^2} + \dfrac{n_s}{S_s^2}}\right]\theta_s \quad \ldots\ldots (7)$$

$$\text{Standard Deviation} \quad \sigma_3 = \sqrt{\frac{1}{\dfrac{1}{\sigma_2^2} + \dfrac{1}{\sigma_s^2}}} = \sqrt{\frac{\sigma_2^2 \times S_s^2}{S_s^2 + n_s\sigma_2^2}} \quad \ldots\ldots (8)$$

To illustrate this last case, it can be assumed that a second sample was collected in Bloomington in some later time and it yielded another trip rate table. This new information is to be used to improve the information already available (which itself is the result of the Lafayette trip rate table updated by the first Bloomington sample). The same cell by cell procedure will be adopted using the revised Eqs. 3 and 4. The computations for the cell corresponding to households of four persons, owning 2 cars: are given below.

Prior information (from previous updating): $\theta_2 = 2.30$; and $\sigma_2 = 0.101$.

New sample information (hypothetical): $\theta_s = 2.55$; $n_s = 55$; and $S_s = 1.72$.

Posterior (Updated) information:

Using Eq. 7,

$$\theta_3 = \frac{\frac{1}{(0.101)^2}}{\frac{1}{(0.101)^2} + \frac{55}{(1.72)^2}} \times 2.30 + \frac{\frac{55}{(1.72)^2}}{\frac{1}{(0.101)^2} + \frac{55}{(1.72)^2}} \times 2.55 = 2.34 \quad \ldots \quad (9)$$

$$\sigma_3 = \frac{(0.101)^2 \times (1.72)^2}{(1.72)^2 + 55 \times (0.101)^2} = 0.093 \quad \ldots \quad (10)$$

If need for further updating arises, the θ_3 and σ_3 just computed can serve as the prior distribution parameters, and the same Eqs. 7 and 8 can be used again by substituting the appropriate values of the prior parameters as well as those of the new sample. The whole idea is to make maximum utilization of the information available prior and up to this point.

Subjective Judgement as a Source of New Information.—Subjective judgement and evaluation of a group of experienced planners and other professionals familiar with study area can serve as a valuable source of new information in lieu of collecting a small disaggregate sample. On the other hand, if no appropriate trip rate table can be borrowed from another study area, the subjective judgement can then serve as the prior information while a small sample could provide the new information.

In order to use subjective information within a Bayesian framework, the primary task is to transform this subjective evaluation into mathematical values of distribution parameters. This can be done by having the group of planners and professionals specify a range within which the mean trip rate for a certain household category will fall, as well as the odds or chances that each member of the group is willing to give that this mean trip rate will fall within the specified range (3). This subjective information can be transformed into a mean and variance after a distribution for the group's judgement about the parameter is assumed.

To illustrate this procedure, the same setting as in the previous example is assumed, except that this time it is assumed that the study area has decided not to conduct any field survey. Instead, the subjective judgement of a group experienced with the area places 4 to 5 odds that the mean home-based work vehicle trip rate of households of four persons, owning two cars lies between 2.1 and 2.7. A normal distribution would be an appropriate distribution to describe the group's feelings about that parameter. The mean of this distribution is 2.4,

and the variance can be calculated considering the fact that four-fifths or 80% of the area under this normal curve falls between 2.1 and 2.7, therefore, $1 - 0.8 = 0.2$ corresponds to the tail areas, i.e., $\alpha = 0.2/2 = 0.1$.

TABLE 2.—Summary of Bayesian Updating Techniques for Trip Generation Rates

Prior		Sample (new)		Posterior distribution parameters (5)
Source (1)	Parameters (2)	Source (3)	Parameters (4)	
General Case	θ_1	general case	θ_s	$\theta_2 = \left[\frac{1/\sigma_1^2}{1/\sigma_1^2 + 1/\sigma_s^2}\right]\times\theta_1 + \left[\frac{1/\sigma_s^2}{1/\sigma_1^2 + 1/\sigma_s^2}\right]\times\theta_s$
	σ_1		σ_s	$\sigma_2 = \sqrt{\frac{\sigma_1^2\times\sigma_s^2}{\sigma_1^2+\sigma_s^2}}$
From already developed trip table, one cell at a time	θ_1	small disaggregate sample	θ_s	$\theta_2 = \left[\frac{n_1/S_1^2}{n_1/S_1^2 + n_s/S_s^2}\right]\times\theta_1 + \left[\frac{n_s/S_s^2}{n_1/S_1^2 + n_s/S_s^2}\right]\times\theta_s$
	n_1, S_1 $\Big\}\ \sigma_1^2 = \frac{S_1^2}{n_1}$		n_s, S_s $\Big\}\ \sigma_s^2 = \frac{S_s^2}{n_s}$	$\sigma_2 = \sqrt{\frac{S_1^2\times S_s^2}{n_1 S_s^2 + n_s S_1^2}}$
From already updated trip rate tables, or from subjective information	θ_1	small disaggregate sample	θ_s	$\theta_2 = \left[\frac{1/\sigma_1^2}{1/\sigma_1^2 + n_s/S_s^2}\right]\times\theta_1 + \left[\frac{n_s/S_s^2}{1/\sigma_1^2 + n_s/S_s^2}\right]\times\theta_s$
	σ_1		n_s, S_s $\Big\}\ \sigma_s^2 = \frac{S_s^2}{n_s}$	$\sigma_2 = \sqrt{\frac{\sigma_1^2\times S_s^2}{S_s^2 + n_s\sigma_1^2}}$
From already developed trip rate table	θ_1	subjective information	θ_s	$\theta_2 = \left[\frac{n_1/S_1^2}{n_1/S_1^2 + 1/\sigma_s^2}\right]\times\theta_1 + \left[\frac{1/\sigma_s^2}{n_1/S_1^2 + 1/\sigma_s^2}\right]\times\theta_s$
	n_1, S_1 $\Big\}\ \sigma_1^2 = \frac{S_1^2}{n_1}$		σ_s	$\sigma_2 = \sqrt{\frac{S_1^2\times\sigma_s^2}{n_1\sigma_s^2 + S_1^2}}$

Using a standard normal distribution table it can be observed that an α of 0.1 corresponds to a Z-value of 1.28. The standard deviation σ_s of this normal distribution can be evaluated from the following:

$$\frac{2.7 - \theta_s}{\sigma_s} = Z \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11a)$$

$$\frac{2.7 - 2.4}{\sigma_s} = 1.28 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11b)$$

$$\text{or,} \quad \sigma_s = 0.234 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11c)$$

All the necessary information is available for calculating the posterior distribution parameters, which is again normal. The formulas for these calculations can be obtained from Eqs. 1 and 3 as:

$$\text{mean,} \quad \theta_2 = \left[\frac{\frac{n_1}{S_1^2}}{\frac{n_1}{S_1^2} + \frac{1}{\sigma_s^2}}\right]\theta_1 + \left[\frac{\frac{1}{\sigma_s^2}}{\frac{n_1}{S_1^2} + \frac{1}{\sigma_s^2}}\right]\theta_s \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

$$\text{Standard Deviation} \quad \sigma_2 = \sqrt{\frac{1}{\sigma_1^2} + \frac{1}{\sigma_s^2}} \rightarrow \sigma_2 = \sqrt{\frac{S_1^2 \times \sigma_s^2}{n_1 \sigma_s^2 + S_1^2}} \quad \ldots\ldots (13)$$

The numerical computations of this example are given below.

Prior Information (from Lafayette HBW trip rate table, Table 1): $\theta_1 = 2.28$; $n_1 = 236$; and $S_1 = 1.652$.

Sample information (subjective): $\theta_s = 2.4$; and $\sigma_s = 0.234$.

Posterior (updated) information:

Using Eq. 12,

$$\theta_2 = \frac{\frac{236}{(1.652)^2}}{\frac{236}{(1.652)^2} + \frac{1}{(0.234)^2}} \times 2.28 + \frac{\frac{1}{(0.234)^2}}{\frac{236}{(1.652)^2} + \frac{1}{(0.234)^2}} \times 2.4 = 2.3 \quad (14)$$

$$S_2 = \sqrt{\frac{(1.652)^2 \times (0.234)^2}{236 \times (0.234)^2 + (1.652)^2}} = 0.098 \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The equations developed for all the cases discussed are summarized in Table 2.

Conclusions

A statistical approach based on Bayesian methodology provides a useful tool for updating trip generation rates and, therefore, improving their accuracy in reflecting the trip making behavior of households. This approach can be used for spatial as well as temporal updating of the trip rates.

Spatial updating is aimed at making trip rates borrowed from a similar urban area more descriptive of the households in the study area. This can be done using a small disaggregate sample collected in the study area or by taking advantage of the local expertise by quantifying the subjective judgement of local planners and other professionals.

Temporal updating is that where trip rates developed at an earlier point in time are updated to better reflect current or anticipated future conditions. Bayesian updating techniques can be used for this purpose as described in this paper, therefore, providing a very powerful tool for a continuing planning effort, whereby new information (objective or subjective) obtained at a relatively low cost can be regularly used to update information available up to that point.

Acknowledgment

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Appendix I.—References

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DISCUSSION

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High Head Performance of Concrete Pipe[a]

Discussion by Wayne W. Smith,[2] M. ASCE

A complete circumferential crack frequently occurs in the relatively thin lining of a high head, prestressed concrete cylinder pipe at or near the back end of the spigot ring. Because deformation due to creep is approximately twice that due to elastic deformation, there is an even greater tendency for this cracking to occur in pipes that have been yarded for some time.

After cracking, the situation is analogous to trying to use a pair of pliers with a broken jaw. The lining and the core cannot, metaphorically speaking, grab the tail of the spigot ring and give it a twist. Instead, only pressure forces applied by the barrel can act upon the embedded portion of the spigot ring. The net result of this condition is that the barrel and spigot do not have the same rotation or slope at the point of union. This relationship tends to complicate the analysis when the spigot is joined to the barrel during an elastic foundation type of analysis.

Contact between the spigot and the barrel tends to be discontinuous and, for that reason, it is convenient to assume a multipoint rather than a continuous type of bearing between the spigot and the barrel. This approach, in turn, requires a matrix or simultaneous equation type of analysis where the pressure on each element of the barrel is equal, and opposite to, the pressure on the corresponding element of the ring. Assuming contact at each point the deflection of the barrel and the ring must also be the same at each point.

An initial solution involving all of the contact points will likely have negative pressure at some point or points, representing the *twisting forces* necessary to make the ring conform to the shape of the barrel. Fig. 12 shows the result of one such set of calculations based on elastic deformation before the occurrence of creep. The large negative pressure at the second point gives a clue as to why the lining is frequently cracked by these forces.

When the lining is indeed cracked, the lining is unable to apply the necessary negative force, effective contact is lost, and the point is, therefore, dropped from the list of pressure points. This process is continued until there is no negative pressure point. The final result for the pipe section in question is shown in Fig. 13.

As yet, this writer has not had occasion to examine the additional effect of creep on the spigot and barrel connection, but it must be considerable.

The theory, as presented in the paper, appears to be couched in rather general terms without many specifics being given. However, the writer is of the opinion that every reasonable effort must be made to get as much as possible of the internal pressure load on the spigot ring into the bell end of the pipe. The

[a]January, 1981, by James W. Davidson (Proc. Paper 15987).

[2]Concrete Pipe Consultant, 16192 Malaga Lane, Huntington Beach, Calif. 92647.

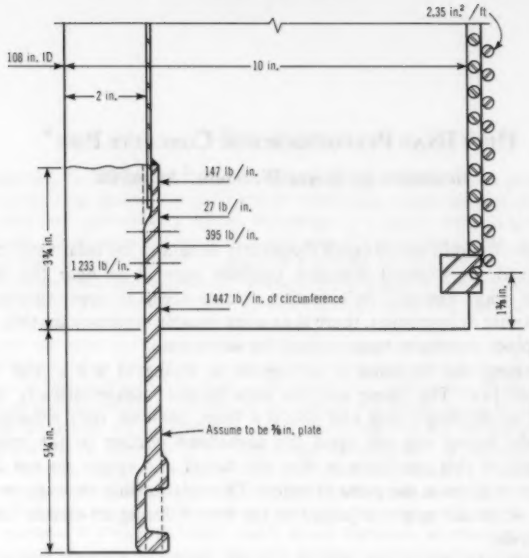

FIG. 12.—Pipe Section with Elastic Deformation before Creep (1 lb/in. = 0.018 kg/mm; 1 in. = 25.4 mm)

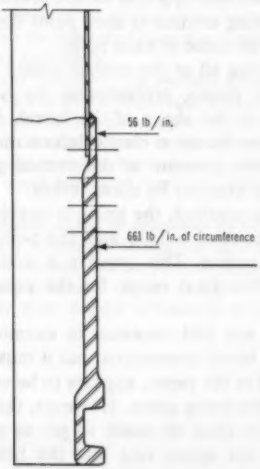

FIG. 13.—Pipe Section with Cracking (1 lb/in. = 0.018 kg/mm)

purpose is dual. The first objective is to prevent overloading the spigot end of the barrel, and the second objective is to expand the bell and thereby prevent severe longitudinal bending stresses that will arise if the barrel is expanded and the bell is not.

In experiments conducted by the writer involving 600-ft head, 30-in. ID, noncylinder prestressed specimens with a 4-in. wall (183-m head, 76.2 cm ID with a 10.1 cm wall), initial tests utilized an ungrouted relatively stiff spigot ring. Failures occurred prematurely. The concrete bell broke away from the barrel in large pieces. Some pieces represented as much as 270° of the pipe's circumference. These failures were obviously due to bending stresses arising from the failure of the unloaded bell to expand along with the barrel. In subsequent tests the joints were grouted and cured before the hydrostatic tests and, except for one improperly grouted joint, this type of failure ceased.

Loading of the spigot to yield may leave a void between the ring and the lining—not an altogether desirable condition. If practical, this condition should be avoided. Possibly, proper and careful grouting before pressurizing is part of the answer.

Designing for an Acceptable Wind Environment[a]

Errata

The following corrections should be made to the original paper:

Page 130, Table 1: Should read as shown herein instead of as shown in the original paper.

---

[a]March, 1981, by Edward A. Arens (Proc. Paper 16132).

TABLE 1.—Wind Effects Versus Standard Equivalent Mean Wind Speed Under Standard Conditions*

Standard equivalent mean wind speed, in meters per second (1)	Effects observed or deduced (2)
0	Calm, no noticeable wind
2	Wind felt on face
	Clothing flaps [5]
	Newspaper reading becomes difficult (1)
4	Hair disarranged [5], dust and paper raised, rain and sleet driven (1)
6	Control of walking begins to be impaired
8	Violent flapping of clothes [5], progress into wind slightly slowed
10	Umbrella used with difficulty
12	Blown sideways [2], inconvenience felt walking into wind, hair blown straight
	Difficult to walk steadily, appreciably slowed into wind [10]
	Noise on ears unpleasant
14	Generally impedes progress
	Almost halted into wind, uncontrolled tottering downwind [10]
16	Difficulty with balance in gusts [2]
18	Unbalanced, grabbing at supports [2]
20	People blown over in gusts [3]
22	Cannot stand [3]

*The minimum gust duration required for each effect to be experienced is given, in seconds, in brackets [ ].

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4. The author's full name, Society membership grade, and a footnote stating present employment must appear on the first page of the paper. Authors need not be Society members.

5. All mathematics must be typewritten and special symbols must be identified properly. The letter symbols used should be defined where they first appear, in figures, tables, or text, and arranged alphabetically in an appendix at the end of the paper titled Appendix.—Notation.

6. Standard definitions and symbols should be used. Reference should be made to the lists published by the American National Standards Institute and to the *Authors' Guide to the Publications of ASCE*.

7. Figures should be drawn in black ink, at a size that, with a 50% reduction, would have a published width in the *Journals* of from 3 in. (76 mm) to 4-1/2 in. (110 mm). The lettering must be legible at the reduced size. Photographs should be submitted as glossy prints. Explanations and descriptions must be placed in text rather than within the figure.

8. Tables should be typed (an original ribbon copy and two duplicates) on one side of 8-1/2-in. (220-mm) by 11-in. (280-mm) paper. An explanation of each table must appear in the text.

9. References cited in text should be arranged in alphabetical order in an appendix at the end of the paper, or preceding the Appendix.—Notation, as an Appendix.—References.

10. A list of key words and an information retrieval abstract of 175 words should be provided with each paper.

11. A summary of approximately 40 words must accompany the paper.

12. A set of conclusions must end the paper.

13. Dual units, i.e., U.S. Customary followed by SI (International System) units in parentheses, should be used throughout the paper.

14. A practical applications section should be included also, if appropriate.